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Geotechnical and Structures Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Dust Abatement Methods for Lines-of-Communication and Base Camps in Temperate Climates

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Final report

Prepared for U.S. Marine Corps Systems Command
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ABSTRACT: The U.S. Army Engineer Research and Development Center was tasked by the U.S. Marine Corps Systems Command to develop dust control systems for sustainment use on roads and other large-area applications in temperate climates as part of a comprehensive dust abatement program. The project consisted of evaluating various dust palliatives and application procedures during field tests. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This report addresses testing performed to evaluate commercial palliatives and application processes for constructing and maintaining lines-of-communication. Twenty-five test sections were constructed at Fort Leonard Wood, MO, using commercial palliatives for dust abatement. Several application procedures were evaluated in the process, including topical applications and admixture applications with alternate application rates. Each test section was evaluated at 0, 30, 80, and 220 days after construction. The evaluation consisted of dust particle collection and soil property measurements. Pertinent conclusions from the testing conducted are noted, and recommendations for selecting dust abatement methods and materials are provided.

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Preface

The purpose of this report is to present results from the evaluation of methods for mitigating dust on unpaved roads subjected to heavy truck traffic for sustainment applications in temperate climates. A sustainment application, as defined in this experiment, is a dust abatement material or method that is designed for long-term use during sustained military operations. The application of dust palliatives for sustainment missions assumes that construction equipment will be available in the theater of operations. Dust abatement materials and application methods must effectively control dust for at least 90 days. This report includes the evaluation of commercially available dust palliatives, as well as alternative methods for applying the products. This report provides data for the following:

a. Evaluating commercially available dust palliatives for mitigating dust on unpaved roads under heavy truck traffic.

b. Evaluating construction procedures to determine the most efficient means of applying dust palliatives for long-term use.

c. Evaluating the effect of traffic type on the effectiveness of dust palliatives.

d. Selecting palliative application rates for treatment of unpaved roads in sustainment environments.

Users of this report include the U.S. Marine Corps Systems Command, units charged with construction of unpaved roads, and agencies assigned operations planning responsibilities.

The project described in this report is part of the Dust Abatement Program currently sponsored by Headquarters, U.S. Marine Corps Systems Command, 2200 Lester Street, Quantico, VA 22134-6050.

This publication was prepared by personnel from the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented in this report are based upon a series of field tests conducted at Fort Leonard Wood, MO, from September 2004 to April 2005. The research team consisted of Messrs. John F. Rushing, Vernon M. Moore, Jeb S. Tingle, Timothy McCaffrey, Quint Mason, and Roosevelt Felix, Airfield and Pavements Branch (APB), GSL.

Messrs. Rushing, Moore, Tingle, Mason, and McCaffrey prepared this publication under the supervision of Mr. Don R. Alexander, Chief, APB; Dr. Albert J. Bush III; Chief, ESMD; and Dr. David W. Pittman, Director, GSL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan was Commander and Executive Director.

Recommended changes for improving this publication in content and/or format should be submitted on DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forwarded to Headquarters, U.S. Army Corps of Engineers, ATTN: CECW-EWS, Kingman Bldg, Rm 321, 7701 Telegraph Road, Alexandria, VA 22315.

Executive Summary

The U.S. Army Engineer Research and Development Center (ERDC) was tasked by the U.S. Marine Corps Systems Command to develop dust control systems for lines-of-communication and base camp operations. This phase of the program included the evaluation of dust abatement technologies for use in temperate climates. The project consisted of field testing dust suppression chemicals and their application procedures. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. The dust palliative field tests discussed in this report were conducted at Fort Leonard Wood, MO, from September 2004 to April 2005 by the ERDC, Vicksburg, MS. This report summarizes the construction, trafficking, and monitoring of 25 field test sections designed to evaluate eight commercially available dust palliatives as well as their application rates and placement procedures. Acrylic polymer emulsions, a polysaccharide, calcium chloride, and synthetic fluids were among the products evaluated in this test. Application procedures included topical applications as well as an admixture procedure to incorporate the chemicals into the soil. Palliative effectiveness was evaluated using dust particle collection equipment and visual observations of product performance. Pertinent conclusions and recommendations from the testing conducted are noted below.

Conclusions

The following conclusions were derived from the application and testing of selected palliatives from September 2004 to April 2005:

a. An Etnyre asphalt emulsion distributor was effective for spraying each of the dust palliatives. It provided a controlled application rate with even distribution. However, using the polymer emulsions in the equipment may cause maintenance problems if the polymers begin to harden in the tank or within the distribution pipes and valves.

b. A TEREX soil reclaimer/stabilizer provided excellent mixing for incorporating the dust palliatives in the respective road section. It also provided precise control over the tilling depth.

c. A 12-ton vibratory compactor was unable to achieve the original density of the road sections with only three coverages. Compactors with greater

mass may be required to achieve maximum density without extending the construction time.

d. Topical applications of 38 percent by weight calcium chloride solution, Durasoil®, and Envirokleen® can provide adequate dust mitigation for roads with a high load-bearing capacity.

e. For crust-forming products such as the polymer emulsions and Surtac®, topical applications are unable to withstand the abrasion from heavy traffic, and disintegration of the surface crust reduces the product's effectiveness.

f. Products placed at the 0.4-gsy application rate using the admix procedure did not provide adequate dust control for extended use.

g. Each dust palliative provided some reduction in dust when compared with untreated road sections.

h. The calcium chloride solution was the most effective dust palliative for all application methods. However, calcium chloride solutions are known to be corrosive to metal.

i. Unpaved roads with soil densities approaching their maximum value are subject to a reduction in their load-bearing capacity if disturbed using the admix procedure. The inability of the compaction process to reestablish the soil density can lead to deterioration of the road surface.

j. Frequent exposure to precipitation is detrimental to the performance of Surtac®. The product did not provide moisture resistance and produced an enhanced deterioration rate of the road surface when placed with the admix procedure.

Recommendations

The following recommendations are given based upon the results of the field tests:

a. Calcium chloride (38 percent solution), Durasoil® (neat), and Envirokleen® (neat) can be placed using a topical application only. Using the admix procedure (*spray/till/compact/spray*) for these products will greatly complicate construction effort without providing comparable benefits in performance.

b. Envirotac II®, M10 + 50®, Soil~Sement®, Soiltac®, and Surtac® should be placed using the procedure *spray/till/compact/spray*. Achieving greater depths with these chemicals will help to stabilize the soil and prolong product effectiveness. The final spray application will provide a greater concentration of product on the surface to resist traffic abrasion.

c. A distribution system comparable to the asphalt emulsion distributor is recommended for applying dust palliatives. The system must be capable of holding significant volumes of fluid and evenly dispersing the fluid via fan-type spray nozzles. Mechanical pumps must be able to generate pressures capable of providing even dispersion across the road. Minimum pump pressures will be dictated by the size and type of spray nozzle used and should be adjusted to meet the manufacturer's recommendations. The distribution system should be able to regulate the volumetric output of the fluids for application rate control. Minimum flow rates of 100 gal/min are recommended for treating large areas.

1 Introduction

The U.S. military was plagued by fugitive dust during Operations Enduring Freedom and Iraqi Freedom. Dust generation was a major concern during military maneuver operations in-theater, and numerous unpaved roads were trafficked with long convoys of military vehicle traffic in both combat and sustainment roles. The surface of the low-volume roads and main supply routes deteriorated under the abrasive action of both wheeled and tracked vehicles. The generation of dust also permeated through the large network of base camps, impacting rear-area support activities and, ultimately, support and stability operations. The widespread accumulation of dust during ground vehicle operations and in base camps adversely impacted the ability of military personnel to effectively conduct combat operations.

The U.S. military is also constantly hindered by dust problems on its installations within the United States and abroad. Dust produced by military equipment often disrupts daily operations and training routines. Many times, inadequate funding prevents surfacing of problematic roads, and the only available option is treating the areas with dust suppressants. Numerous chemical materials have been marketed in recent years as being able to effectively provide dust mitigation, but differentiating the most beneficial products is difficult because of the lack of well-documented, controlled dust palliative studies.

The U.S. Army Engineer Research and Development Center (ERDC) was tasked by the U.S. Marine Corps Systems Command to develop a dust control system for sustainment use on roads and other large-area applications in temperate climates. The project consisted of evaluating various dust palliatives and application procedures under controlled laboratory conditions and during field tests. The products of this research will include construction equipment recommendations, palliative recommendations, and complete application guidance.

Objective

The primary objectives of this evaluation were to develop recommendations for dust palliatives as well as procedures for applying products in a sustainment environment, principally roads and base camps at military installations or within the theater of operations. This report provides data for the following:

a. Evaluating commercially available dust palliatives for mitigating dust on unpaved roads under heavy truck traffic.

b. Evaluating construction procedures for the most efficient means of applying dust palliatives for long-term use.

c. Evaluating the effect of traffic type on the effectiveness of dust palliatives.

d. Selecting palliative application rates for treatment of unpaved roads in sustainment environments.

The testing initiated in this evaluation represents the third phase of a comprehensive dust abatement program designed to develop dust control systems for both expeditionary use on Forward Area Refueling Points and sustainment use on roads and other large-area applications. The results of the overall program will provide the U.S. Marine Corps with the equipment, products, and criteria for mitigating dust in the theater of operations and on local installations.

Scope

A dust control exercise was scheduled for 8-16 September 2004 at Fort Leonard Wood, MO, to evaluate construction procedures for application of dust palliatives for use in sustainment operations. The Fort Leonard Wood Range Control provided a section of unpaved road for use during the test (POC: Joe Proffitt, DPW, Fort Leonard Wood). The test included the assessment of commercial-off-the-shelf (COTS) dust palliatives along with the evaluation of application rates and procedures for product placement. Eight COTS products touted as being effective at controlling airborne dust were acquired by the ERDC and evaluated during the test. Twenty-five test sections were constructed using these products at various application rates and with different application procedures. Additional testing was performed at intervals of approximately 30, 80, and 220 days from palliative placement to identify methods for long-term dust control. This document briefly describes the application equipment/procedures evaluated and provides results from each evaluation period. Final recommendations are based upon observation of the long-term effectiveness of the applied products at reducing airborne dust.

2 Background

Test Site Description

The field tests were conducted on the Fort Leonard Wood, MO military reservation. The specific test sites for the field experiment were located on training routes FLW 5, FLW 20, and FLW 28 and on a heavily used road within Training Area 244. The U.S. Army extensively uses these unpaved roads for training soldiers to operate large military vehicles in convoys. Figure 1 provides a layout of the site and the location of the test sections. Global Positioning System (GPS) coordinates for the beginning and end of each section are given in Table 1.

The site is located physiographically in the Salem Plateau section of the Ozark Plateau province in an area of low hills. The subgrade material contains many rock fragments and is predominantly reddish gravelly sandy clays, which are classified as either a CL or CH under the Unified Soil Classification System (USCS), underlain with dolomite and limestone (Grau 2001). Figure 2 provides the USCS classification of the road surface.

Climatic data were obtained from the weather station at Forney Army Airfield at Fort Leonard Wood. Temperature and precipitation data are presented in Table 2. The average mean daily minimum and maximum temperatures are 47 ^{o}F (8 ^{o}C) and 66 ^{o}F (19 C), respectively. The average annual rainfall and snowfall for the region are 45.4 in. (1153 mm) and 18 in. (457 mm), respectively.

Dust Palliatives

The materials used in this evaluation are commercially available for purchase in quantities ranging from 5-gallon containers to 5,000-gallon tanker trucks. The cost of the products ranges from $0.40/gallon to $10.00/gallon depending on their chemical composition. Most of the products are miscible with water and are intended to be diluted from their “as received” concentration.

Polymer Emulsions

The products Envirotac II®, M10 +50®, Soil~Sement®, and Soiltac® are classified as polymer emulsions. These products are generally vinyl acetate or acrylic-based copolymers suspended in an aqueous phase by surfactants. They typically consist of 40 to 50 percent solid particles by weight of emulsion. Once they are applied, the polymer particles begin to coalesce as the water evaporates from the system, leaving a soil-polymer matrix that prevents small dust particles from escaping the surface. The polymers used for dust control typically have excellent tensile and flexural strength, adhesion to soil particles, and resistance to water.

Figure 1. Layout of test sections

Table 1
GPS Coordinates of Test Sections

Section	Start			End		
	N	W	Elev, ft	N	W	Elev, ft
1	37° 43.206'	92° 11.941'	1178	37° 43.251	92° 11.830'	1138
2	37° 43.266'	92° 11.973'	1117	37° 43.326'	92° 11.696'	1107
3	37° 43.454'	92° 11.537'	1089	37° 43.496'	92° 11.407'	1075
4	37° 43.676'	92° 11.145'	1044	37° 43.770'	92° 11.094'	1041
5	37° 43.851'	92° 10.890'	1028	37° 43.898'	92° 10.777'	1021
6	37° 44.120'	92° 10.197'	1022	37° 44.126'	92° 10.071'	1034
7	37° 44.122'	92° 09.879'	1072	37° 44.178'	92° 09.773'	1079
8	37° 44.223'	92° 09.543'	1126	37° 44.244'	92° 09.773'	1126
9	37° 44.278'	92° 09.557'	1098	37° 44.373'	92° 09.508'	1111
10	37° 44.590'	92° 09.627'	1140	37° 44.680'	92° 09.688'	1140
11	37° 44.713'	92° 09.739'	1129	37° 44.757'	92° 09.855'	1116
12	37° 44.840'	92° 09.967'	1123	37° 44.939'	92° 10.007'	1111
13	37° 44.991'	92° 10.015'	1120	37° 45.095'	92° 09.991'	1108
14	37° 45.194'	92° 09.997'	1137	37° 45.290'	92° 10.028'	1132
15	37° 45.290'	92° 10.028'	1132	37° 45.392'	92° 10.020'	1162
16	37° 45.663'	92° 09.989'	1105	37° 45.762'	92° 09.998'	1066
17	37° 45.499'	92° 09.999'	1130	37° 45.600'	92° 09.991'	1116
18	37° 43.506'	92° 11.231'	1052	37° 43.502'	92° 11.100'	1077
19	37° 43.502'	92° 11.100'	1077	37° 43.498'	92° 10.971'	1041
20	37° 43.498'	92° 10.971'	1041	37° 43.495	92° 10.842'	1019
21	37° 43.332'	92° 09.615'	1084	37° 43.225'	92° 09.627'	1090
22	37° 43.072'	92° 09.640'	1092	37° 42.975'	92° 09.642'	1082
23	37° 42.975'	92° 09.642'	1082	37° 42.877'	92° 09.644'	1086
24	37° 43.495'	92° 10.842'	1019	37° 43.492'	92° 10.716'	1053
25	37° 42.861'	92° 09.645'	1094	37° 42.759'	92° 09.639'	1084

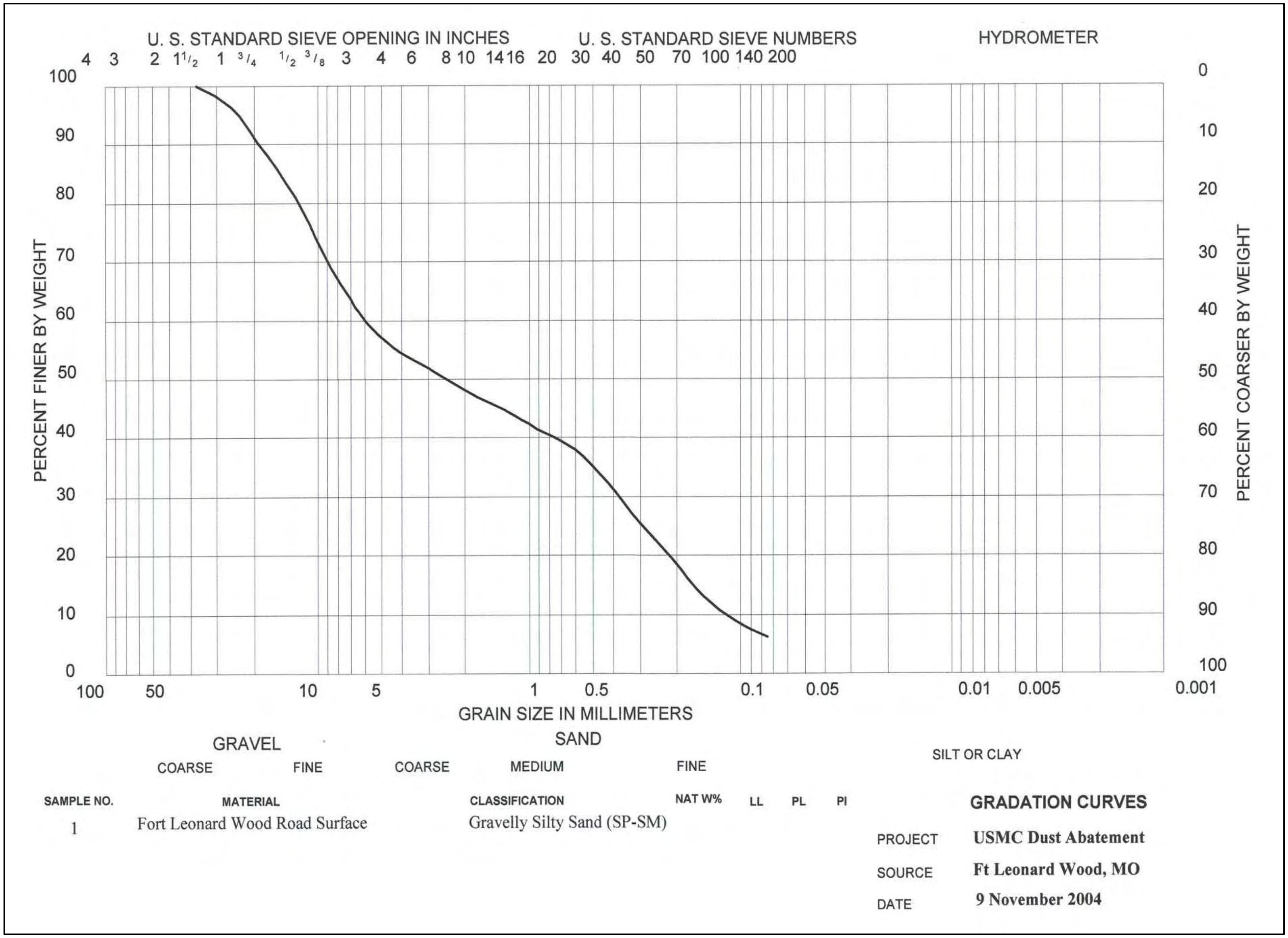

Figure 2. Soil gradation curve

Table 2
Climatological Data Summary

	J	F	M	A	M	J	J	A	S	O	N	D	ANN	YRS REC
Temperature, °C (°F)														
Highest	25 (77)	28 (83)	29 (84)	35 (95)	33 (91)	38 (100)	43 (109)	41 (105)	38 (100)	34 (94)	28 (83)	23 (74)	43 (109)	24
Mean Daily Max	4 (40)	7 (44)	13 (56)	20 (68)	24 (75)	28 (83)	31 (88)	30 (86)	26 (79)	21 (69)	13 (56)	6 (43)	19 (66)	24
Mean Daily Min	-4 (24)	-3 (27)	3 (37)	9 (48)	13 (56)	18 (65)	21 (69)	19 (67)	16 (60)	9 (49)	3 (38)	-2 (28)	8 (47)	24
Lowest	-25 (-13)	-22 (-8)	-20 (-4)	-5 (23)	-1 (31)	0 (32)	9 (49)	8 (47)	1 (34)	-5 (23)	-15 (5)	-26 (-15)	-26 (-15)	24
Precipitation, mm (in.)														
Mean	51 (2.0)	64 (2.5)	97 (3.8)	117 (4.6)	124 (4.9)	104 (4.1)	91 (3.6)	97 (3.8)	112 (4.4)	91 (3.6)	107 (4.2)	86 (3.4)	1153 (45.4)	24
Snowfall, mm (in.)														
Mean	142 (5.6)	114 (4.5)	84 (3.3)	10 (0.4)	0	0	0	0	0	# (#)	30 (1.2)	81 (3.2)	457 (18)	24
Relative Humidity, %														
Mean														24
0500 LST	79	81	76	75	82	85	86	86	85	78	76	77	81	
1500 LST	56	53	49	45	53	56	51	50	54	47	54	57	52	

Source of data: *www.afccc.af.mil/climo Fort Leonard Wood/Forney AAF Missouri*
# Denotes less than 1 mm (0.05 in.).

Synthetic Fluids

Durasoil® and Envirokleen® are synthetic organic fluids that are designed to be applied to a soil "as received." These fluids are not miscible with water and therefore are unable to be diluted. They consist of isoalkanes that do not dry or cure with time. The reworkable binder is ready for immediate use upon application and maintains effectiveness over extended periods of use.

Calcium Chloride

A calcium chloride solution was purchased from Scottwood Industries, Inc., and delivered in a 4,000-gallon tanker truck. The solution contained 38 percent calcium chloride by weight. This deliquescent material has been used for many years as a low-cost solution for dust problems. It maintains effectiveness by absorbing moisture from the air and binding soil particles together. Long-term efficiency of calcium chloride is sometimes limited because the material is water-soluble and will leach from the soil with prolonged exposure to rainfall. Calcium chloride is also known to be a corrosive material and may increase maintenance requirements for vehicles using roads on which it has been sprayed.

Polysaccharide

Surtac® is a polysaccharide based system composed of sugar, starch, and surfactants suspended in an aqueous solution. It is shipped in a concentrated form that may be diluted depending upon its intended use. Surtac® provides dust abatement by encapsulating soil particles and creating a binding network throughout the treated area. The binder is water-soluble and reworkable. However, it is also susceptible to leaching from the soil with heavy rainfall.

Evaluation Procedures

Several evaluation tools were used to determine the effectiveness of each dust abatement method on the constructed test sections. Soil classification and in situ property measurements allowed researchers to understand the mechanisms by which the dust palliatives worked. Dust collection systems were used to quantify the amount of material dislodging from the road surface upon applied traffic. An unsurfaced road condition rating was used to monitor the formation and progression of surface distresses over time. Overall recommendations were based upon the data obtained and the visually perceived mitigation of dust.

Soil Classification

Soil samples were collected from various test sections and subjected to a sieve analysis and Atterberg limit tests. The gradation curve for the soil is plotted in Figure 2. The soil is a non-plastic gravelly silty sand (SP-SM) according to the USCS.

Nuclear Density and Moisture Measurements

A Troxler® 3430 nuclear gauge was used to collect density and moisture data in the center of each test section prior to construction and after each evaluation period (Photo 1). The gauge contains two radioactive sources: Cesium-137 for density measurement and Americium-241:Beryllium for determining moisture content. Density measurements were taken in the 6-in. direct transmission mode after creating a hole in the section using a drill rod according to ASTM D2922. Moisture contents were obtained using procedures outlined in ASTM D3017.

Dynamic Cone Penetrometer (DCP) Measurements

DCP tests were conducted according to the procedure described by American Society for Testing and Materials (ASTM) D6951 (2003). The DCP had a 60 deg cone with a base diameter of 0.79 in. The test procedure involved placing the DCP cone point on the surface and driving the cone into the ground surface until the base of the cone was flush with the surface. Next, a baseline measurement was recorded to the nearest 5 millimeters. The 17.6-lb hammer was then raised and dropped 22.6 in. onto an anvil, which drove the penetrometer rod and cone into the soil. Depth of the cone penetration measurements and number of hammer blows were recorded approximately every inch (25 mm) or whenever any noticeable change in penetration rate occurred. A DCP strength index in terms of penetration per hammer blow was calculated for each measurement interval. The DCP index was then converted to California Bearing Ratio (CBR) percentage using the correlation $CBR = 292/DCP^{1.12}$ where DCP is in millimeters/blow. The CBR value ranges from 0 to 100 percent and provides an index of relative soil strength. DCP data for this report were processed using a Microsoft Excel spreadsheet. Photo 2 illustrates the use of the DCP on a treated test section.

Stationary Dust Sampling

The stationary dust collection system consisted of two dust collectors manufactured by Andersen Samplers, Inc. (model # BM2200H). Each collector consisted of a paper filter placed over a wire mesh screen through which a slight vacuum pressure was drawn using an electric vacuum pump (Photo 3). The two samples were placed 20 ft apart in the center of the test section on the downwind side. A Ford 1-ton pickup with dual rear wheels was used to traffic the section and create dust for collection (Photo 4). Ten vehicle passes were made over the section at a speed of 30 mph. Upon completion, the filters were removed, weighed, and compared to their initial weights to determine the amount of material collected.

Mobile Dust Sampling

A mobile dust sampler was built by the ERDC for use during the Fort Leonard Wood dust tests (Photo 4). The unit contained a modified dust collector similar to those used for stationary testing. An aluminum shell with a 2-in. diameter intake nozzle was placed over the top of the filter. A slight vacuum, drawn through an electric vacuum pump, pulled dusty air from behind the vehicle and through the filter. The filter was then removed, weighed, and compared to its initial weight to determine the amount of material collected. The system was mounted onto a bar attached to the receiver of the towing package on the test vehicle. The intake nozzle was located 8 ft behind the vehicle and 3 ft above the ground. The same Ford 1-ton truck was used to collect the mobile dust samples. Ten vehicle passes were made over each test section at a speed of 30 mph. The vacuum was controlled from within the cab of the test vehicle by attaching a rheostat between the generator and dust sampler to turn power on and off. Testing was performed in the center 500 ft of the test sections to avoid interference by the untreated areas at their ends.

Visual Inspection Rating

During the dust collection process, each section was given a rating based upon the visually perceived effectiveness of the dust palliative used. This rating was on a scale from one (blinding dust) to ten (no visible dust). The numerical ratings correlate to the clarity of the air behind a vehicle traveling the test section. For example, a very dusty section may have visibility reduced to about 30 percent of what it would be prior to vehicle movement. This section would receive a three for the visual rating. The initial value for each section prior to treatment was considered to be 1. Immediately after treatment, each section was given a rating of 10. This method allowed researchers to differentiate product effectiveness among the different test sections and to determine the validity of the results from the dust collection procedures.

Additionally, an unsurfaced condition survey procedure was used to evaluate the deterioration of the road surface over time. The procedure is described by Eaton et al. (1987). An unsurfaced pavement condition index (PCI) of 100 was assigned to each admix section immediately after treatment. The topical sections on FLW 5 were assigned an initial PCI of 85, and the topical sections located in Training Area 244 were assigned an initial PCI of 95.

Initial Site Characterization

Soil Data

The nuclear gauge and the DCP were used to collect in situ soil property data prior to application of dust palliatives. These data were compared with data collected after test section construction to identify changes in bearing capacity or moisture content of the roadbed. The results from the initial data collection are shown in Tables 3 and 4.

Table 3
Pretreatment Density and Moisture Data

Section	Wet Density lb/ft^3)	Moisture lb/ft^3)	Dry Density (lb/ft^3)	Moisture (%)
1	138.1	5.8	132.3	4.4
2	139.0	6.4	132.6	4.8
3	130.7	9.0	121.8	7.4
4	138.1	6.3	131.8	4.8
5	140.2	4.8	135.5	3.5
6	132.7	7.4	125.4	5.9
7	139.0	5.7	133.3	4.3
8	141.7	4.2	137.5	3.0
9	133.4	9.5	123.9	7.6
10	139.5	5.4	134.2	4.0
11	138.3	4.7	133.6	3.5
12	136.4	3.7	132.7	2.8
13	140.5	5.7	134.7	4.2
14	139.4	5.2	134.1	3.9
15	139.6	4.9	134.7	3.6
16	140.8	5.1	135.7	3.8
17	138.6	3.8	134.7	2.8
18	142.3	4.2	138.1	3.0
19	137.3	7.4	129.9	5.7
20	134.8	6.9	127.9	5.4
21	144.4	5.2	139.3	3.7
22	148.3	5.1	143.2	3.5
23	141.3	7.4	134.1	5.5
24	136.4	4.6	131.8	3.5
25	146.5	3.6	142.9	2.5
Average:	**139.1**	**5.7**	**133.4**	**4.3**

Table 4
Pretreatment DCP Data

Section	Surface		Subgrade	
	Depth (in.)	CBR (%)	Depth (in.)	CBR (%)
1	0 - 4	100	6 - 12	20
4	0 - 4	100	refusal	
8	0 - 4	100	refusal	
12	0 - 4	100	refusal	
16	0 - 4	100	refusal	
20	0 - 4	100	refusal	

Preliminary Dust Data

The ERDC performed data collection on each of the test sections prior to any construction or treatment to acquire baseline data for comparison among test sections as well as for determining the initial reduction in dust upon palliative placement. Both the stationary and mobile dust collection systems were used during this evaluation. The data collected are presented in Table 5.

Table 5
Pretreatment Dust Collection Data

Section	Dust Collected (g)	
	Stationary	Mobile
1	1.027	0.241
2	1.224	0.131
3	1.279	0.172
4	1.560	0.182
5	0.855	0.141
6	1.631	0.155
7	0.846	0.162
8	1.040	0.162
9	2.518	0.214
10	1.491	0.219
11	1.598	0.127
12	0.810	0.119
13	1.229	0.140
14	1.368	0.180
15	1.280	0.191
16	1.061	0.188
17	1.749	0.219
18	2.016	0.194
19	2.264	0.190
20	1.266	0.175
21	0.654	0.131
22	0.637	0.413
23	0.756	0.409
24	1.348	0.155
25	1.197	0.251

3 Test Section Construction

Project Plan

The dust palliative evaluation was designed to investigate product performance and to identify the most desirable application procedure for material placement. Dust palliatives were applied using both an admix and a topical procedure. Different application rates were also used for products in order to identify the minimum material quantity needed for the desired performance. The experiment was also designed to evaluate dust palliative performance with different types of traffic. Some of the test sections were constructed in areas principally trafficked by heavy wheeled vehicles, and some were placed in areas subject to tracked vehicle maneuver operations. Fort Leonard Wood was chosen as the location for this test for two main reasons. First, as a major training facility for equipment operators, Fort Leonard Wood offered numerous unpaved roads subjected to frequent traffic in order to accurately identify the effectiveness of commercially available dust palliatives. Secondly, Fort Leonard Wood also is located in a region that has a temperate climate and receives substantial amounts of precipitation throughout the year. Some of the dust palliatives tested were believed to be susceptible to leaching from the soil with exposure to precipitation.

Section Construction

The ERDC borrowed, leased, or supplied the construction equipment used during the evaluation. The palliatives were sprayed onto the road surface using an Etnyre asphalt emulsion distributor (Photo 5). For the sections treated with the admix procedure, a TEREX RS-325B soil stabilizer/reclaimer was used to till the surface of the road and to distribute the products (Photo 6). The ends of the test sections were leveled using a 35 HP Kubota L3410 HST tractor with a loader and Land Pride box blade, and the road was then compacted using a Caterpillar CS-563D 12-ton vibratory roller (Photo 7). Other equipment included a TEREX 5-K forklift for loading/unloading materials (Photo 8) and an Easy Lawn C125 1,250-gal hydroseeder for storing additional water assets.

Each test section was 600 ft long with an average width of 25 ft. Traffic delineators were placed at the ends of each section for identification (Photo 9). An initial prewetting of the road surface was applied to break the surface tension of the soil and allow for product penetration and also to increase the moisture content of the soil for compaction.

Sections 1 through 8 were located on training route FLW 20. Traffic on these sections consisted of convoys of heavy wheeled vehicles, with occasional tracked vehicles. Each product along this route was placed with a heavy application rate (0.8 gsy) using an admix procedure. Sections 9 through 17 were located on FLW 5. This road had similar traffic to the previous sections, but did not appear to have been traveled by tracked vehicles. The application rates on these sections were lower than the previous sections, and some topical applications were used along this road. Sections 18, 19, 20, and 24 on FLW 28 had a wide variety of traffic. A large number of privately owned vehicles (POVs) used this access route along with convoys and some tracked vehicles. The remaining test sites (Sections 21, 22, 23, and 25) were located near the equipment washrack of Training Area 244. This location has multiple types of traffic, including many tracked vehicles. The following paragraphs detail the chemicals and procedures used for constructing each of the test sections. The total product amounts for each section are given in Table 6.

Section 1

The first section (admix) was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Envirotac II® solution. Both the water and palliative were placed with two passes of the Etnyre asphalt emulsion distributor. The section was tilled to a depth of 2 in. to distribute the palliative using three passes of the TEREX soil stabilizer/reclaimer. The outer edges of the road were admixed first followed by a third pass of the TEREX soil stabilizer down the center of the road. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Envirotac II® was applied to the road topically with the Etnyre distributor to provide a sealed wearing surface. The final surface had polished wheel paths with loose gravel covering approximately 5 to 10 percent (Photo 10).

Section 2

The second section was constructed in the same manner as Section 1 but was treated with Soiltac®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Soiltac® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX soil stabilizer/reclaimer. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Soiltac® was applied to the road topically to provide a sealed wearing surface. The final surface had polished wheel paths with loose gravel on approximately 10 to 15 percent.

Table 6
Palliative Application Quantities by Section

Section	Palliative	Additive Amounts (gal)					Application Procedure
		Product	Dilution Ratio[1]	Water	Total[2]	Application Rate (gsy)	
1	Envirotac II®	350	3:1	1000	1350	0.8	Admix
2	Soiltac®	350	3:1	1000	1350	0.8	Admix
3	M10 + 50®	275	3:1	1075	1350	0.8	Admix
4	Soil~Sement®	350	3:1	1000	1350	0.8	Admix
5	Surtac®	350	3:1	1000	1350	0.8	Admix
6	Calcium chloride	1350	neat	0	1350	0.8	Admix
7	Durasoil®	1350	neat	0	1350	0.8	Admix
8	Envirokleen®	1350	neat	0	1350	0.8	Admix
9	Water	0	neat	1350	1350	0.8	Admix
10	Soiltac®	175	3:1	525	700	0.4	Admix
11	Envirotac II®	175	3:1	525	700	0.4	Admix
12	Surtac®	175	3:1	525	700	0.4	Admix
13	Calcium chloride	675	neat	0	675	0.4	Topical
14	Durasoil®	675	neat	0	675	0.4	Topical
15	Envirotac II®	175	3:1	525	700	0.4	Topical
16	Water	0	neat	675	675	0.4	Topical
17	Soiltac®	175	3:1	525	700	0.4	Topical
18	Surtac®	350	3:1	1000	1350	0.8	Admix
19	Durasoil®	1350	neat	0	1350	0.8	Admix
20	Envirotac II®	350	3:1	1000	1350	0.8	Admix
21	Calcium chloride	675	neat	0	675	0.4	Topical
22	Durasoil®	675	neat	0	675	0.4	Topical
23	Surtac®	175	3:1	525	700	0.4	Topical
24	Water	0	neat	1350	1350	0.8	Admix
25	Envirotac II®	175	3:1	525	700	0.4	Topical

[1] Approximate dilution ratios. Actual value may be slightly higher or lower.
[2] Total product amount placed in distributor. Approximately 650 gal was used for 0.4-gsy application rate and 1300 gal for 0.8-gsy application rate.

Section 3

The third section used the same construction method to place another polymer emulsion, M10 + 50®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:M10+50® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and M10 + 50® was applied to the road topically to provide a sealed wearing surface. The final surface had polished wheel paths with loose gravel covering approximately 15 to 20 percent.

Section 4

The fourth section used the same construction method to place Soil~Sement®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Soil~Sement® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Soil~Sement® was applied to the road topically to provide a sealed wearing surface. The section had a smooth, tight final surface.

Section 5

The fifth section used the same construction method to place Surtac®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Surtac® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Surtac® was applied to the road topically to provide a sealed wearing surface. The section had a smooth, tight final surface with polished wheel paths and loose gravel covering less than 5 percent (Photo 11).

Section 6

The sixth section was treated with a 38 percent by weight solution of calcium chloride. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of the calcium chloride solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of the calcium chloride solution was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a smooth, tight final surface with some large 3 to 5 in. cobble intermittently covering the surface. The section had a dark appearance with an opalescent sheen (Photo 12).

Section 7

The seventh section was treated with Durasoil®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of Durasoil®. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of the Durasoil® was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a smooth surface with polished wheel paths that were slightly rutted. Loose aggregate covered approximately 2 percent of the surface area at the northeast end. The Durasoil® caused the soil to appear much darker than the surrounding material (Photo 13).

Section 8

The eighth section was treated with Envirokleen®. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of Envirokleen®. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of the Envirokleen® was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a rough surface due to large rocks within the soil. The aggregate in this area was noticeably larger than any of the other treated sections. The dust palliative caused the section to appear very dark colored.

Section 9

The ninth section was constructed as a control section. This was the first section that was built in the evaluation in order to identify any flaws in the proposed construction process. The section was sprayed with 0.4 gsy of water and tilled to a depth of 4 in. with the TEREX. It was evident that tilling to a 4-in. depth penetrated below the gravel surface and incorporated additional fines into the surface layer from the subgrade, thereby weakening the roadbed. It was also determined that the moisture content of the soil would be too dry to obtain optimum compaction levels without spraying any additional water. The decision was made during construction of this section to prewet the remaining sections to increase the moisture content. Construction resumed on Section 9 by leveling the ends of the section with the Kubota tractor and then compacting with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of water was applied to the road to maintain consistency with future application procedures. The section had a tight surface with some rough areas due to poor construction.

Section 10

Sections 10 through 12 were designed to test the effect of application rate on dust palliative performance. They were each constructed in the same manner as the previous sections but using one-half of the product amounts. Two polymer emulsions and one polysaccharide were chosen for these sections. Section 10 was first prewet with 0.4 gsy of water and then sprayed with 0.2 gsy of a 3:1 water:Soiltac® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.2 gsy of the 3:1 water and Soiltac® solution was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a smooth surface with scattered loose gravel (1/2-in. max) covering 60 percent of the area.

Section 11

The eleventh section was treated with Envirotac II®. The section was first prewet with 0.4 gsy of water and then sprayed with 0.2 gsy of a 3:1 water:Envirotac II® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.2 gsy of the 3:1 solution of water and Envirotac II® was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a smooth surface with rough ends due to insufficient leveling of the tilled soil. The surface was abrading under traffic and was covered with loose gravel on approximately 50 to 60 percent of the area.

Section 12

The twelfth section was treated with Surtac®. The section was first prewet with 0.4 gsy of water and then sprayed with 0.2 gsy of a 3:1 water:Surtac® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.2 gsy of the 3:1 solution of water and Surtac® was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section had a smooth surface with scattered loose gravel (1/2-in. max) covering 60 percent of the area.

Section 13

Sections 13 through 17 were designed to test the effect of application procedures on dust palliative performance. They were each constructed using topical applications of 0.4 gsy after an initial prewet with 0.4 gsy of water. Two polymer emulsions, one calcium chloride solution, and one synthetic fluid were chosen for these sections, along with one section treated with only water for comparison. Section 13 was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 38 percent by weight solution of calcium chloride. The section had a rough surface with potholes and scattered loose aggregate covering the entire area. The calcium chloride produced a significant color change to the section and provided visual evidence of its location (Photo 14).

Section 14

Section 14 was treated with a topical application of Durasoil®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of Durasoil®. The section had some densification in the wheel paths and scattered loose gravel over 60 to 70 percent of the surface. The Durasoil® produced a significant color change to the section and provided visual evidence of its location (Photo 15).

Section 15

Section 15 was treated with a topical application of Envirotac II®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Envirotac II® solution. The section had no significant color change and had loose aggregate covering the entire surface. The section was difficult to visually distinguish from untreated areas, but it did display immediate dust abatement (Photo 16).

Section 16

Section 16 was treated with water as a control section for product evaluation. It was first prewet with 0.4 gsy of water and then sprayed with an additional 0.4 gsy of water. The section exhibited no significant color change and had loose aggregate covering the entire surface. The section was difficult to visually distinguish from untreated areas.

Section 17

Section 17 was treated with a topical application of Soiltac®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Soiltac® solution. The section exhibited no significant color change and had loose aggregate covering the entire surface. The section was difficult to visually distinguish from untreated areas, but it did display immediate dust abatement.

Section 18

Sections 18, 19, 20, and 24 on FLW 28 were constructed using an admix procedure with total application rates of 0.8 gsy. These sections were identical to selected sections placed on FLW 20. The traffic exposure in these locations, however, is somewhat different. This location is traveled by significantly more POVs and lightweight equipment than the sections on FLW 20. The road is an access route to the rear gate of the installation as well as a heavily used training facility. Section 18 was treated with Surtac® using the same process as used in Section 5. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Surtac® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Surtac® was applied to the road topically to provide a sealed wearing surface. The section had a smooth, tight final surface with approximately 30 percent of the area covered in loose gravel.

Section 19

Section 19 was treated with Durasoil® using the same process as used in Section 7. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of Durasoil®. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of Durasoil® was applied to the road topically to increase the effectiveness of dust abatement at the surface. The section was dark in color and had a smooth, tight final surface with polished wheel paths and less than 5 percent of the area covered in loose gravel.

Section 20

Section 20 was treated with Envirotac II® using the same process as used in Section 1. The section was prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Envirotac II® solution. The section was tilled to a depth of 2 in. using three passes of the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of a 3:1 solution of water and Envirotac II® was applied to the road topically to provide a sealed wearing surface. The section had a smooth, tight final surface with polished wheel paths and approximately 10 percent of the area covered in loose gravel.

Section 21

Sections 21, 22, 23, and 25 were designed to test the effect of application procedures and traffic patterns on dust palliative performance. They were each constructed using topical applications of 0.4 gsy after an initial prewet with 0.4 gsy of water. One calcium chloride solution, one synthetic fluid, one polysaccharide, and one polymer emulsion were chosen for these sections. Section 21 was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 38 percent by weight solution of calcium chloride. The section had a dark-colored surface with scattered loose aggregate covering the entire area.

Section 22

Section 22 was treated with a topical application of Durasoil®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of Durasoil®. The section had a dark-colored surface that was covered in loose aggregate. The Durasoil® appeared to be integrating with the hard surface and assisting some 1/2-in. aggregate with embedding in the surface.

Section 23

Section 23 was treated with a topical application of Surtac®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1

water:Surtac® solution. The section had no significant color change and had loose aggregate covering the entire surface. The section was difficult to visually distinguish from untreated areas, but it did display immediate dust abatement.

Section 24

Section 24 was constructed as an additional control section. The section was prewet with 0.4 gsy of water and then sprayed with an additional 0.4 gsy of water and tilled to a depth of 2 in. with the TEREX. The ends of the section were smoothed using the Kubota tractor, and the section was compacted with three coverages of the 12-ton vibratory roller. A final 0.4 gsy of water was applied to the road topically to maintain consistency with other application procedures. The section had a tight surface that produced considerable dust due to fines abrading from the surface.

Section 25

Section 25 was treated with a topical application of Envirotac II®. It was first prewet with 0.4 gsy of water and then sprayed with 0.4 gsy of a 3:1 water:Envirotac II® solution. The section had no significant color change and had loose aggregate covering the entire surface. The section was difficult to visually distinguish from untreated areas, but it did display dust abatement.

Baseline Data Collection

Soil Data

The nuclear density gauge and the DCP were used to collect in situ soil property data after application of dust palliatives. These data were compared with data collected prior to test section construction to identify changes in bearing capacity or moisture content of the roadbed. The results from the post-treatment data collection are shown in Tables 7 and 8.

The average dry density and moisture content of the sections after construction were 129.6 pcf and 4.7 percent, respectively. The moisture content of the sections increased slightly from its original value of 4.3 percent prior to construction. This was expected since water was added to each section during the palliative application process. The dry density of the sections decreased after construction from 133.4 lb/ft^2 to 129.6 lb/ft^2. Using the rotary mixer to till the road surface disrupts the soil particles and weakens the roadbed, initially. Under optimum moisture conditions the density can be returned to its original state. However, because of time constraints, compaction was limited to three coverages. This did not allow for the soil to reach the same density it had prior to construction. As the sections are permitted to cure and additional moisture is lost, the sections are expected to return to higher densities with additional traffic.

The bearing capacity of the road is related to the CBR values calculated from DCP tests. It was observed that the admix construction process decreased the strength of the road, as evidenced from DCP data on Sections 1 and 4. Prior to treatment, each section had a CBR of 100 percent near the road surface. The decrease in the CBR of the surface layer of some of the road sections most likely resulted from the reduction in density at the road surface after using the admix construction procedure. The sections that were treated with a topical application retained their strength.

Table 7
Post-treatment Density and Moisture Data

Section	Wet Density (lb/ft^3)	Moisture (lb/ft^3)	Dry Density (lb/ft^3)	Moisture (%)
1	134.2	6.5	127.7	5.1
2	137.6	5.3	132.3	4.0
3	128.2	8.7	119.6	7.2
4	128.2	7.4	120.8	6.1
5	136.5	4.9	131.6	3.7
6	129.4	8.9	120.5	7.4
7	137.3	6.3	131.0	4.8
8	135.3	5.6	129.7	4.3
9	127.7	8.0	119.7	6.6
10	127.9	3.7	124.1	3.0
11	125.0	4.7	130.3	3.6
12	132.3	4.1	128.2	3.2
13	139.8	4.6	135.2	3.2
14	137.2	6.0	131.3	4.5
15	139.0	3.5	135.5	2.6
16	138.8	6.9	131.9	5.2
17	136.9	5.3	131.7	4.0
18	132.6	6.9	125.7	5.5
19	137.6	7.0	130.6	5.4
20	135.1	6.7	128.5	5.2
21	141.2	4.6	136.7	3.3
22	148.8	5.4	143.4	3.7
23	135.0	10.2	124.8	8.2
24	134.9	5.3	129.7	4.1
25	142.6	4.2	138.4	3.0
Average:	**135.2**	**6.0**	**129.6**	**4.7**

Table 8
Post-treatment DCP Data

Section	Surface		Subgrade	
	Depth (in.)	CBR (%)	Depth (in.)	CBR (%)
1	0 - 4	80	4 - 12	40
4	0 - 4	70	6 - 12	20
7	0 - 6	100	refusal	
8	0 - 4	100	refusal	
12	0 - 4	100	refusal	
14	0 - 4	100	refusal	
17	0 - 4	100	refusal	
19	0 - 4	100	refusal	
20	0 - 4	100	refusal	
22	0 - 6	50	8 - 16	15

Stationary Dust Collection Data

Stationary dust collection was performed on 15 and 16 September 2004. Results were compared with data collected prior to palliative application. Table 9 gives the number of grams of dust collected and the percentage of dust reduction due to treatment.

The data indicate that the dust palliatives were very effective at reducing dust immediately after application. The initial effectiveness of the product did not appear to be affected by the construction process used. Topical treatments exhibited dust control capabilities similar to admixed treatments during this initial evaluation. The sections that were the least effective were those treated with water. However, water-treated sections did appear to have some benefit over untreated areas. It was difficult to differentiate the product effectiveness immediately after construction since all products tested displayed positive characteristics.

Table 9 Post-treatment Stationary Dust Collection Data			
Section	**Palliative**	**Dust Collected (g)**	**Reduction from Pretreatment Data (%)**
1	Envirotac II®	0.047	95
2	Soiltac®	0.061	95
3	M10 + 50®	0.185	86
4	Soil~Sement®	0.134	91
5	Surtac®	0.058	93
6	Calcium chloride	0.003	100
7	Durasoil®	0.006	99
8	Envirokleen®	0.022	98
9	Water	1.744	31
10	Soiltac®	0.196	87
11	Envirotac II®	0.357	78
12	Surtac®	0.266	67
13	Calcium chloride	0.054	96
14	Durasoil®	0.050	96
15	Envirotac II®	0.060	95
16	Water	0.281	74
17	Soiltac®	0.074	96
18	Surtac®	0.136	93
19	Durasoil®	0.084	96
20	Envirotac II®	0.432	66
21	Calcium chloride	0.052	92
22	Durasoil®	0.018	97
23	Surtac®	0.081	89
24	Water	1.658	-23
25	Envirotac II®	0.081	93
Range of Values:		**0.003 - 1.744**	**-23 - 100**

Mobile Dust Collection Data

Mobile dust collection was also performed on 15 and 16 September 2004. The results were compared with the data collected prior to palliative application. Table 10 gives the number of grams of dust collected and the percentage of dust reduction due to treatment.

Table 10 Post-treatment Mobile Dust Collection Data			
Section	**Palliative**	**Dust Collected (g)**	**Reduction from Pretreatment Data (%)**
1	Envirotac II®	0.053	78
2	Soiltac®	0.015	89
3	M10 + 50®	0.096	44
4	Soil~Sement®	0.060	67
5	Surtac®	0.061	57
6	Calcium chloride	0.023	85
7	Durasoil®	0.025	85
8	Envirokleen®	0.067	59
9	Water	0.288	-35
10	Soiltac®	0.089	59
11	Envirotac II®	0.117	8
12	Surtac®	0.063	47
13	Calcium chloride	0.025	82
14	Durasoil®	0.020	89
15	Envirotac II®	0.033	83
16	Water	0.046	76
17	Soiltac®	0.031	86
18	Surtac®	0.032	84
19	Durasoil®	0.028	85
20	Envirotac II®	0.065	63
21	Calcium chloride	0.024	82
22	Durasoil®	0.020	95
23	Surtac®	0.047	89
24	Water	0.145	6
25	Envirotac II®	0.064	75
Range of Values:		**0.015 - 0.288**	**-35 - 95**

The data indicate that the dust palliatives were generally effective at reducing dust immediately after application. The initial effectiveness of the product did not appear to be affected by the construction process used. Topical treatments exhibited dust control capabilities similar to admix treatments during this initial evaluation. Some variation existed in these data, which was not generated during the stationary dust collection. These discrepancies appear to be attributed to the mobile dust collection system since visual observations generally agree with the results of the stationary collection system results. It was difficult to differentiate the product effectiveness immediately after construction since all products tested displayed positive characteristics. The sections that were the least effective were those treated with water. Even these did appear to have some benefit over untreated areas.

4 Dust Palliative Evaluation

Military operations are often constrained by time and equipment needs when occurring in remote locations. It is imperative that materials and processes chosen for dust suppression make optimum use of the resources available to the personnel involved. The length of time that a material successfully mitigates dust needs to be maximized to reduce unnecessary waste of materials and manpower. The continued monitoring of dust suppressants over time provides the information necessary to identify the minimum requirements for dust mitigation.

30-Day Data Collection

The first interval for data collection occurred from 19-21 October 2004. This evaluation occurred approximately 1 month after the initial construction period. The tests included both soil property measurements and dust collection. The weather conditions during the evaluation are expected to have had some impact on the results of the tests. High humidity and low evening temperatures resulted in light precipitation each morning during the evaluation period. Dust collection was not initiated until the roads dried considerably, but none of the untreated sites were as dusty as they had been prior to construction.

30-Day Soil Data

The nuclear density gauge and the DCP were used to collect in situ soil property data 30 days after application of dust palliatives. These data were compared with data collected after test section construction to identify changes in bearing capacity or moisture content of the roadbed. The results from the 30-day soil data collection are summarized in Tables 11 and 12.

The average dry density of the test sections increased from 129.6 pcf to 131.5 pcf during the first month after construction. This densification of the roads did not have a significant impact on the bearing capacity. The CBR of all of the sections was similar to the values recorded during the post-construction testing. Most of the sections had CBR values of 100 percent with the exception of Sections 1, 4, and 9. Each of these sections was constructed using the admix construction method, suggesting that this procedure weakened the surface of the road. Section 9 had a very low CBR value compared with each of the other sections. The loss of strength was evidenced by severe rutting from heavy traffic. The poor strength of the road surface on this section is attributed to construction errors when the mixing depth reached below the aggregate layer and introduced a significant increase in the concentration of fines in the soil. The average moisture content for each section was greater than it was during the previous tests. Several days of precipitation prior to the evaluation exposed the road to moisture without allowing time for it to dry.

Table 11
30-Day Density and Moisture Data

Section	Wet Density (lb/ft^3)	Moisture (lb/ft^3)	Dry Density (lb/ft^3)	Moisture (%)
1	134.8	7.4	127.4	5.8
2	141.8	6.8	135.0	5.0
3	130.2	7.8	122.3	6.4
4	133.1	11.8	121.2	9.8
5	141.4	7.0	134.4	5.2
6	133.3	10.3	123.0	8.4
7	132.5	8.0	124.5	6.4
8	141.1	7.1	133.9	5.3
9	134.3	15.2	119.0	12.8
10	138.9	6.0	132.9	4.5
11	141.9	7.4	134.6	5.5
12	140.4	6.3	134.1	4.7
13	141.9	5.6	136.2	4.1
14	140.5	6.1	134.4	4.5
15	140.8	5.7	135.1	4.2
16	135.8	9.6	126.2	7.6
17	137.0	5.0	131.9	3.8
18	134.3	6.8	127.5	5.3
19	139.1	7.5	131.6	5.7
20	138.5	7.0	131.5	5.3
21	143.0	5.1	137.9	3.7
22	145.2	4.8	140.5	3.4
23	145.8	4.8	141.1	3.4
24	139.2	6.5	132.7	4.9
25	144.4	6.4	138.0	4.7
Average:	**138.8**	**7.3**	**131.5**	**5.6**

Table 12 30-Day DCP Data				
	Surface		Subgrade	
Section	Depth (in.)	CBR (%)	Depth (in.)	CBR (%)
1	0 - 4	85	6 - 12	70
4	0 - 4	60	8 - 12	40
7	0 - 6	100	8 - 16	12
8	0 - 6	100	9 - 18	18
9	0 - 4	10	4 - 12	15
12	0 - 6	100	refusal	
14	0 - 6	100	6 - 14	100
17	0 - 4	100	4 - 8	100
19	0 - 4	100	4 - 8	100
20	0 - 4	100	4 - 8	100

30-Day Stationary Dust Collection Data

Table 13 presents the data obtained from the stationary dust collectors approximately 30 days after palliative placement. The data indicate that many of the products were effective for dust mitigation 1 month after the initial construction. The level of effectiveness did vary among products and placement procedures. Products placed at 0.8 gsy using the admix procedure were generally more effective than either those constructed using the lower application rate or the topically placed products. Photos 17-40 illustrate the relative amounts of dust on the test sections during the evaluation.

Calcium chloride was the most effective palliative during the 30-day evaluation. It outperformed the other products using both the admix and topical application procedure. Weather conditions enhanced its effectiveness during testing. The high humidity and light precipitation allowed the deliquescent material to pull moisture from the air to aid in dust mitigation.

The synthetic fluids, Envirokleen® and Durasoil®, also performed very well in the 30-day evaluation. Durasoil® and Envirokleen®, unlike other products, appeared to work as well when placed topically as they did when incorporated into the road surface. These sections also exhibited a significant increase in strength under traffic as indicated by the DCP data.

The polysaccharide product, Surtac®, was very effective during the 30-day evaluation on all the sections in which it was placed. It did exhibit some binding characteristics and prevented major surface deterioration.

The polymer emulsions, Envirotac II®, Soiltac®, M10 + 50®, and Soil~Sement®, performed well for dust control, but their ability to prevent dust was affected by the manner in which they were placed. The sections placed with the admix procedure worked very well and retained a smooth, tough surface.

They were affected by the heavy tracked vehicle traffic, and exhibited some surface wear and rutting. The sections placed topically did not appear to be nearly as effective as those mixed in the soil and compacted. Abrasion from traffic dislodged most of the gravel on the surface and created some dust during traffic. Differences in the individual products were not great enough to eliminate any from continued evaluation during the 30-day evaluation.

Table 13
30-Day Stationary Dust Collection Data

Section	Palliative	Dust Collected (g)	Reduction from Pretreatment Data (%)	Reduction from Section 16 (%)	Visual Rating
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.580	44	20	7
2	Soiltac®	0.100	92	86	9
3	M10 + 50®	0.732	43	0	6
4	Soil~Sement®	0.319	80	56	7
5	Surtac®	0.159	81	78	8
6	Calcium chloride	0.033	98	95	10
7	Durasoil®	0.198	77	73	9
8	Envirokleen®	0.161	85	78	9
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.456	69	37	7
11	Envirotac II®	0.079	95	89	9
12	Surtac®	0.187	77	74	9
FLW 5 0.4 gsy Topical					
13	Calcium chloride	0.326	73	55	7
14	Durasoil®	0.165	88	77	9
15	Envirotac II®	0.764	40	0	5
16	Water	0.724	32	0	5
17	Soiltac®	0.431	75	40	6
FLW 28 0.8 gsy Admix					
18	Surtac®	0.151	93	79	9
19	Durasoil®	0.055	98	92	10
20	Envirotac II®	0.409	68	44	6
24	Water	0.634	59	12	3
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.047	72	94	10
22	Durasoil®	0.181	81	75	9
23	Surtac®	0.143	53	80	9
25	Envirotac II®	0.486	53	33	4

30-Day Mobile Dust Collection Data

Data from the mobile dust sampler (Table 14) generally agree with the stationary dust collector data. Some variability exists in the data, and the mobile collection system appears to be less consistent than the stationary unit. Similar trends to the stationary system can be seen in product performance with the mobile unit. The most effective product was the calcium chloride, followed by the synthetic fluids and then the polysaccharide and polymer emulsions.

Table 14
30-Day Mobile Dust Collection Data

Section	Palliative	Dust Collected (g)	Reduction from Pretreatment Data (%)	Reduction from Section 16 (%)	Visual Rating
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.102	58	0	7
2	Soiltac®	0.048	63	44	9
3	M10 + 50®	0.076	56	11	6
4	Soil~Sement®	0.066	64	22	7
5	Surtac®	0.039	72	54	8
6	Calcium chloride	0.034	78	60	10
7	Durasoil®	0.038	77	55	9
8	Envirokleen®	0.031	81	64	9
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.055	75	35	7
11	Envirotac II®	0.052	59	39	9
12	Surtac®	0.055	54	35	9
FLW 5 0.4 gsy Topical					
13	Calcium chloride	0.148	0	0	7
14	Durasoil®	0.052	71	39	9
15	Envirotac II®	0.066	65	22	5
16	Water	0.085	55	0	5
17	Soiltac®	0.121	45	0	6
FLW 28 0.8 gsy Admix					
18	Surtac®	0.084	57	1	9
19	Durasoil®	0.020	89	76	10
20	Envirotac II®	0.092	47	0	6
24	Water	0.175	0	0	3
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.027	79	68	10
22	Durasoil®	0.055	87	35	9
23	Surtac®	0.047	89	45	9
25	Envirotac II®	0.092	63	0	4

Several of the test sections were beginning to exhibit surface distresses from traffic and environmental exposure. Photos 41-44 illustrate some of these distresses and the location in which they occurred. Most of the sections treated with the admix procedure had some degree of rutting in the vehicle wheelpaths. This phenomenon most likely occurs because of the inability to achieve the original density of the soil during construction. Further densification occurred when heavy vehicles traversed the sections (Photo 42). Rut depths were more severe in the sections treated with non-binding chemicals.

Along with rutting, the crust-forming materials exhibited longitudinal cracking in the road surface. High stress concentrations from heavy vehicles caused the surface coat to crack, providing locations for moisture intrusion in the road (Photo 43). This occurrence can lead to further deterioration with prolonged exposure to precipitation and continued traffic.

Some of the sections compacted during the construction process were beginning to have aggregate dislodge from the surface. This was more prevalent for Sections 10 through 12 where the concentration of palliative was reduced to 0.4 gsy. The chemicals in these sections were unable to effectively bind the aggregate at the lower concentration (Photo 44).

80-Day Data Collection

The second evaluation scheduled for 18-20 November 2004 was postponed because of the significant amount of precipitation that occurred during the previous week. Therefore, the second evaluation occurred 1-4 December 2004. The tests included both soil property measurements and dust collection. Although the road surfaces were given sufficient time to dry, the high amount of precipitation preceding the evaluation saturated the ground such that it had an observable effect on the amount of dust collected. Photos 45-60 illustrate the amount of dust produced by the test vehicle during this evaluation.

80-Day Soil Data

The nuclear density gauge and the DCP were used to collect in situ soil property data 80 days after application of dust palliatives. These data were compared with data collected after the initial test section construction to identify changes in bearing capacity or moisture content of the roadbed. The results from the 80-day data collection are shown in Tables 15 and 16.

The average dry density of the test sections increased from 131.5 pcf to 133.4 pcf during the 2-month period after the first evaluation as the result of heavy vehicles densifying the soil. The CBR of most sections tested was higher during the second evaluation. The average moisture content had increased from 5.6 to 6.6 percent during the 2-month period after construction. The moisture content increase was most likely the result of several days of precipitation prior to the evaluation.

Table 15
80-Day Density and Moisture Data

Section	Wet Density (lb/ft^3)	Moisture (lb/ft^3)	Dry Density (lb/ft^3)	Moisture (%)
1	143.5	8.6	134.9	6.4
2	145.6	7.5	138.1	5.4
3	134.9	10.8	124.1	8.7
4	134.5	10.2	124.3	8.2
5	142.8	6.3	136.5	4.6
6	144.0	7.9	136.2	5.8
7	141.2	9.7	131.5	7.4
8	144.2	8.1	136.0	6.0
9	135.6	14.1	121.5	11.6
10	142.0	8.1	133.9	6.1
11	144.4	7.8	136.6	5.7
12	142.0	7.3	134.7	5.5
13	143.1	7.8	135.3	5.7
14	141.9	7.4	134.4	5.5
15	145.9	6.8	139.1	4.9
16	140.2	9.1	131.1	7.0
17	142.3	7.6	134.7	5.6
18	134.5	7.2	127.3	5.6
19	140.1	10.1	130.0	7.8
20	142.4	9.8	132.6	7.4
21	144.9	7.3	137.6	5.3
22	149.3	9.3	140.0	6.6
23	139.2	10.6	128.5	8.3
24	145.2	9.9	135.3	7.3
25	148.2	8.0	140.2	5.7
Average:	**142.1**	**8.7**	**133.4**	**6.6**

Table 16
80-Day DCP Data

Section	Depth (in.)	CBR (%)
1	0 - 2	80
4	0 - 2	80
7	0 - 2	80
8	0 - 2	100
12	0 - 2	100
14	0 - 2	80
17	0 - 2	70
19	0 - 2	100
20	0 - 2	80
22	0 - 2	70

80-Day Stationary Dust Collection Data

The stationary dust collection data (Table 17) indicate many products continued to be effective in reducing dust nearly 3 months after placement. The degree of effectiveness varied among the products placed and the application procedure used. Data suggest that calcium chloride was the most effective dust palliative (Photo 50). The 0.4-gsy topical application quantitatively appears to be the most effective method. The calcium chloride absorbed and withheld moisture, because of high humidity and reoccurring rainfall.

Table 17
80-Day Stationary Dust Collection Data

Section	Palliative	Dust Collected (g)	Reduction from Pretreatment Data (%)	Reduction from Section 16 (%)	Visual Rating
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.754	27	0	7
2	Soiltac®	0.698	43	0	6
3	M10 + 50®	0.415	68	0	6
4	Soil~Sement®	1.354	13	0	4
5	Surtac®	0.346	60	0	4
6	Calcium chloride	0.464	72	0	7
7	Durasoil®	1.051	0	0	3
8	Envirokleen®	1.461	0	0	4
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.860	42	0	7
11	Envirotac II®	0.037	98	67	9
12	Surtac®	0.551	32	0	8
FLW 5 0.4 gsy Topical					
13	Calcium chloride	0.048	96	58	9
14	Durasoil®	0.030	98	73	8
15	Envirotac II®	0.398	69	0	6
16	Water	0.113	89	0	7
17	Soiltac®	0.105	94	7	6
FLW 28 0.8 gsy Admix					
18	Surtac®	1.746	13	0	5
19	Durasoil®	0.926	59	0	6
20	Envirotac II®	0.383	70	0	8
24	Water	0.509	62	0	3
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.062	91	45	9
22	Durasoil®	0.241	62	0	9
23	Surtac®	0.658	13	0	3
25	Envirotac II®	0.149	88	0	7

The polymer emulsions (Envirotac II®, Soiltac®, M10+50®, and Soil~Sement®) applied topically or mixed with aggregate were not as effective in reducing dust as they were during the previous evaluation (Photos 45-48). The sections applied topically were more successful in preventing distresses than the admixed applications. However, this could have been a result of the admixed sections being located on weaker roadbeds. The admixed sections were located in high-traffic volume areas that consisted of various vehicles such as the HMMWV, 113 Army personnel carriers (tracked vehicles), and a family of medium tactical vehicles (2.5- and 5-ton). The traffic broke the bond between the aggregate and polymer, which in turn caused loose aggregate, numerous potholes, and in some cases heavy rutting.

The 0.4-gsy topical products generally reduced the amount of dust more than the other application procedures. Data indicated the 0.4-gsy topical applications of calcium chloride, Durasoil®, Surtac®, and Envirotac II® were the most effective in reducing dust (Photos 53-55). However, data collected from the sections located by the washrack probably are not comparable to the 30-day evaluation data because these sections had been graded twice.

The polysaccharide product, applied topically or mixed with aggregate, was generally not as effective during the 80-day evaluation (Photo 49). The significant amount of precipitation that occurred prior to the evaluation may have dissolved or washed the product from the surface of the aggregate.

The control section was more successful in reducing dust than in the previous evaluation (Photo 58). This could have resulted from the high amount of precipitation that occurred between evaluations. The high amount of water saturated the ground and created enough surface tension that the dust was unable to escape the surface.

80-Day Mobile Dust Collection Data

Data from the mobile dust collectors (Table 18) generally agree with the data collected from the stationary dust collectors. The 0.4-gsy topical application of calcium chloride was the most effective dust palliative. The 0.4-gsy topical applications of Envirotac II® and Soiltac® were not as effective as the calcium chloride. Probably, the heavy trafficking resulted in breaking of the hardened surface created by the polymer emulsions. The 0.8-gsy admix applications of Envirotac II® and Soiltac® were not as effective as the topical applications of the same products.

The 0.8-gsy admix application of the synthetic fluids (Durasoil® and Envirokleen®) were not as effective as the polymer applications. The surfaces of the synthetic fluid test sections were not able to endure as much traffic as the polymer applications. The mobile dust collectors indicated that the 0.8-gsy admix applications of Soil~Sement®, Surtac®, and Durasoil® were completely ineffective in mitigating dust. This could have resulted from the high traffic volume in these sections.

Table 18 80-Day Mobile Dust Collection Data					
Section	**Palliative**	**Dust Collected (g)**	**Reduction from Pretreatment Data (%)**	**Reduction from Section 16 (%)**	**Visual Rating**
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.061	75	61	7
2	Soiltac®	0.095	27	100	6
3	M10 + 50®	0.041	76	8	6
4	Soil~Sement®	0.213	0	100	4
5	Surtac®	0.185	0	100	4
6	Calcium chloride	0.134	14	100	7
7	Durasoil®	0.247	0	100	3
8	Envirokleen®	0.116	28	100	4
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.078	64	100	7
11	Envirotac II®	0.048	62	26	9
12	Surtac®	0.041	66	8	8
FLW 5 0.4 gsy Topical					
13	Calcium chloride	0.020	86	0	9
14	Durasoil®	0.046	74	21	8
15	Envirotac II®	0.044	77	16	6
16	Water	0.038	80	0	7
17	Soiltac®	0.05	77	32	6
FLW 28 0.8 gsy Admix					
18	Surtac®	0.217	0	100	5
19	Durasoil®	0.168	12	100	6
20	Envirotac II®	0.098	62	100	8
24	Water	0.063	27	66	3
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.051	89	61	9
22	Durasoil®	0.164	77	60	9
23	Surtac®	0.290	80	29	3
25	Envirotac II®	0.256	62	0	7

The 0.4-gsy topical application of polysaccharide was more effective than the 0.8-gsy admix application. This could have occurred because of the significant precipitation along with the high volume of vehicles that trafficked the admix section.

80-Day Unsurfaced Road Condition Index Survey

The visual evaluation of the roads included two different procedures: (1) subjective dust generation evaluation and (2) rating unsurfaced roads. The subjective evaluation involves visually rating, on a scale of one to ten (one meaning the highest amount of dust and ten meaning the least amount of dust), each section by the amount of dust generated by the traffic vehicle.

Rating unsurfaced roads involves visually evaluating each section for seven different types of distresses. The distresses include improper cross section, inadequate roadside drainage, corrugations, dust, potholes, ruts, and loose aggregate. The distress measurements are used to calculate an unsurfaced road condition index (URCI). The URCI is a number between 0 to 100 with 0 meaning the road has completely failed and 100 meaning that the road is in excellent condition. The URCI is a tool to determine an approximate cost to repair necessary roads. The URCI for each section is shown in Table 19. Illustrations of each distress type are shown in Photos 61-66.

According to the URCI survey, the polymer applications received a higher rating than all other products. The topical applications of the polymer received a higher rating than the admixed applications. The polymer applications were followed by the calcium chloride applications. The topical applications of the calcium chloride received a higher rating than the admixed applications. The calcium chloride applications were followed by the synthetic fluid applications. The topical applications of the synthetic fluids received a higher rating than the admixed applications. The synthetic fluid applications were followed by the polysaccharide applications. The topical applications of the polysaccharide received a higher rating than the admixed applications.

The URCI evaluation generally disagrees with the data collected from the stationary and mobile dust collectors. The dust collectors generally agreed that calcium chloride was the most effective palliative. The polymers received a higher URCI rating because they were more effective in preventing potholes. The soil-polymer matrix formed prevented water from entering the surface, in turn causing potholes by the addition of high volume traffic. The polysaccharide product was the least effective in preventing potholes. The significant amount of precipitation that occurred between evaluations probably allowed the material to leach from soil.

The narrow margin between polymer and calcium chloride ratings indicate that it would not be possible to select a dust abatement product based solely on URCI evaluation. A specific dust collection experiment, as performed in this study, is necessary to properly select a palliative if dust is the primary concern. However, if rehabilitating an unsurfaced road based on distress types other than dust, an URCI evaluation would probably be a sufficient method.

Table 19
80-Day Unsurfaced Road Condition Index

Section	Distress Types: Improper Cross Section (lin ft)			Inadequate Roadside Drainage (lin ft)			Corrugations (sq ft)			Dust			Potholes (No.)			Ruts (sq ft)			Loose Aggregate (lin ft)			URCI
	Distress Quantity and Severity																					
Section	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	URCI
1				1200						X			20			900			600			83
2				1200							X					700			600			86
3										X						1200			1200			84
4												X	28	3		1800			1200			73
5				1200								X	250	15								68
6				1200						X			40			1800			1200			76
7				1200								X	350	30		800			1200			60
8					1200						X		400						1800			61
9	200	300			1200								50			600	2400					67
10					1200		100			X			50			1200			1200			78
11				1200									45	3		600			600			84
12				1200						X			200			1200			1200			71
13				1200									100	10					1200			82
14				1200									150	3					1200			77
15											X		10						1800			89
16										X			8			1200			1800			82
17										X			80						1800			86
18											X		300	50		400			400			64
19				1200							X		200	15		1200			600			69
20										X			20			500			600			86
21													100						1200			86
22							1000			X									1200			91
23												X	200						1800			72
24										X			3			600			600			86
25											X		20						1800			89

220-Day Data Collection

The final evaluation was scheduled to take place at the end of the winter season. To collect appreciable dust to differentiate section performance, it was necessary to wait until the average daily temperatures reached 65 ^{o}F. High frequency of snow and rain events forced this evaluation to take place 25-29 April 2005. This evaluation period was approximately 220 days after the initial construction of the test sections. This extended period of exposure to heavy traffic and environmental changes led to significant formation and progression of surface distresses on the road surface. In the time interval between the 80-day evaluation and this final evaluation, it became necessary to perform typical road maintenance, which most likely consisted of blading the road surface with a motor grader and establishing a new grade. The condition of the road was far superior to surface conditions observed during the 80-day evaluation, but the maintenance procedures used to remove surface distresses may have caused deterioration of the dust mitigating properties of some of the palliatives. Other data may be skewed by a rain event that occurred 2 days prior to the evaluation. The road had a high moisture content that may have decreased the strength of the subgrade and also reduced the amount of dust collected during traffic. Dust collection data were not obtained on Sections 18, 19, 20, and 24 because a rain event took place during the allocated testing period. Photos 67-74 illustrate the relative effectiveness of the dust palliatives during this evaluation.

220-Day Soil Data

The nuclear gauge and the DCP were used to collect in situ soil property data 220 days after application of dust palliatives. These data were compared with data collected after the initial test section construction and also with data collected during the previous evaluations to identify changes in bearing capacity or moisture content of the roadbed due to traffic or maintenance procedures. The results from the 220-day data collection are shown in Tables 20 and 21.

The average dry density of the test sections did not significantly change from the previous value of 133.4 pcf during the winter season. The average density was also very similar to the values obtained during preconstruction data collection. This suggests that the road surface has been compacted by heavy traffic to values approaching the maximum density for this soil. The CBR of all of the sections tested was 100 percent at the road surface. Because of high-strength crusts at the surface, the DCP was unable to penetrate the surface to assess the subgrade strength in most sections. The average moisture content had not changed from 6.6 percent during this evaluation. Moderately heavy precipitation during several days prior to each of these evaluations most likely influenced these data.

Table 20
220-Day Density and Moisture Data

Section	Wet Density (lb/ft^3)	Moisture (lb/ft^3)	Dry Density (lb/ft^3)	Moisture (%)
1	136.5	8.8	127.7	6.9
2	136.0	11.0	125.0	8.6
3	132.2	12.0	120.2	10.0
4	139.4	8.8	130.7	6.7
5	142.5	7.7	134.7	5.7
6	141.4	8.1	133.3	6.1
7	141.4	11.2	130.2	8.6
8	139.0	9.0	130.0	6.9
9				
10	140.8	7.7	133.1	5.8
11	144.8	7.9	136.8	5.8
12	142.9	7.6	135.3	5.6
13	143.0	9.2	133.8	6.9
14	143.8	7.5	136.3	5.5
15	142.6	6.5	136.1	4.8
16	141.7	9.3	132.5	7.0
17	144.5	7.2	137.3	5.3
18	143.1	9.5	133.6	7.1
19	143.4	8.8	134.6	6.6
20	135.4	9.8	125.6	7.8
21	145.2	8.0	137.2	5.8
22	149.9	7.5	142.4	5.3
23	145.6	10.1	135.5	7.4
24	139.8	8.8	131.1	6.7
25	149.5	7.8	141.6	5.5
Average:	**141.9**	**8.7**	**133.1**	**6.6**

Table 21
220-Day DCP Data

Section	Surface		Subgrade	
	Depth (in.)	CBR (%)	Depth (in.)	CBR (%)
1	0 - 4	100	refusal	
4	0 - 5	100	8 - 16	20
8	0 - 5	100	8 - 16	10
12	0 - 6	100	8 - 16	60
16	0 - 6	100	refusal	
20	0 - 6	100	refusal	
22	0 - 4	100	refusal	

220-Day Stationary Dust Collection Data

The stationary dust collection data (Table 22) indicate that few products maintained their initial effectiveness in reducing dust more than 7 months after placement. Most of the test sections had visibly indiscernible dust mitigating properties. Additionally, the concentration of airborne dust behind the test vehicle on treated sections was very similar to concentrations behind the test vehicle on untreated portions of the road. Data and visual evidence suggest that calcium chloride was the most effective dust palliative (Photo 67). The 0.4-gsy

Table 22
220-Day Stationary Dust Collection Data

Section	Palliative	Dust Collected (g)	Reduction from Pretreatment Data (%)	Reduction from Section 16 (%)	Visual Rating
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.473	54	27	5
2	Soiltac®	0.317	74	51	5
3	M10 + 50®	0.520	59	20	4
4	Soil~Sement®	0.371	76	43	6
5	Surtac®	0.654	24	0	4
6	Calcium chloride	0.187	89	71	9
7	Durasoil®	0.347	59	46	4
8	Envirokleen®	0.618	41	4	4
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.403	73	38	4
11	Envirotac II®	0.399	75	38	4
12	Surtac®	0.737	9	0	4
FLW 5 0.4 gsy Topical					
13	Calcium chloride	0.164	87	75	8
14	Durasoil®	0.483	65	25	5
15	Envirotac II®	0.553	57	14	5
16	Water	0.646	39	0	5
17	Soiltac®	0.626	64	3	4
FLW 28 0.8 gsy Admix					
18	Surtac®				
19	Durasoil®				
20	Envirotac II®				
24	Water				
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.235	64	64	7
22	Durasoil®	0.934	0	0	5
23	Surtac®	0.402	47	38	4
25	Envirotac II®	0.377	69	42	4

topical application quantitatively appears to be less effective than the 0.8-gsy admix construction method. The calcium chloride absorbed and withheld moisture, because of the high humidity and reoccurring rainfall.

The polymer emulsions (Envirotac II®, Soiltac®, M10+50®, and Soil~Sement®) applied topically or mixed with aggregate were not visibly effective in reducing dust during the final evaluation. However, stationary dust collection data indicate that their effectiveness ranged from a 50- to 75-percent reduction in dust from the pretreatment condition and a 20- to 50-percent reduction in dust from the control section. The significant reduction in dust from the initial conditions most likely was observed because of the high moisture content of the road from the precipitation that occurred in the days preceding the evaluation. This observation is supported by the 39-percent reduction in dust of the control section from the initial data collection.

Of the other products tested using the 0.8-gsy admix construction method, the two synthetic fluids, Durasoil® and Envirokleen®, performed similarly to the polymer emulsions according to both visual evidence and stationary dust collection data. The polysaccharide product, Surtac®, was the only product considered to be ineffective at reducing dust. The calcium chloride solution was the most effective product in the evaluation. This section generated considerably less dust as evidenced by both dust collection data and visual observations.

The 0.4-gsy admix products produced data similar to the data collected for the heavier application rate. The two polymer emulsions gave moderate reductions in dust while the polysaccharide product was considered ineffective.

All other data represent products placed topically using an application rate of 0.4 gsy. The calcium chloride solution was the most effective product, reducing dust from 60 to 90 percent over initial conditions and 65 to 75 percent over the control section. Sections treated with calcium chloride were noticeably darker in color than adjacent road sections. The salt did not appear to leach from the road surface during the 220 days after construction was completed as initially predicted. Other data suggest that polymer emulsions applied topically performed similarly to the same product incorporated into the road surface. Data also suggest that the performance of Surtac® was enhanced by using only a topical application. However, special precaution should be used when analyzing data from topical application on the washrack area. High wind velocities with frequent gusts and direction shifts occurred during testing of these sections. Some influence on the data obtained is expected to have occurred from adverse testing conditions.

220-Day Mobile Dust Collection Data

Data from the mobile dust collection system (Table 23) showed little benefit from the dust palliatives 220 days after product placement for reductions in dust concentrations from both pretreatment data and the control section. Most of the data generally agree with the visual observations made regarding the dust concentration in the air as the test vehicle traversed the test sections. The product showing the greatest benefit was calcium chloride. This product was also more successful at reducing dust when placed using the 0.8-gsy admix construction method. Other data suggest small improvements in dust reduction using topical applications of Durasoil® and calcium chloride.

Table 23
220-Day Mobile Dust Collection Data

Section	Palliative	Dust Collected (g)	Reduction from Pretreatment Data (%)	Reduction from Section 16 (%)	Visual Rating
FLW 20 0.8 gsy Admix					
1	Envirotac II®	0.243	0	0	5
2	Soiltac®	0.173	0	11	5
3	M10 + 50®	0.386	0	0	4
4	Soil~Sement®	0.258	0	0	6
5	Surtac®	0.214	0	0	4
6	Calcium chloride	0.093	40	52	9
7	Durasoil®	0.325	0	0	4
8	Envirokleen®	0.233	0	0	4
FLW 5 0.4 gsy Admix					
10	Soiltac®	0.211	4	0	4
11	Envirotac II®	0.212	0	0	4
12	Surtac®	0.226	0	0	4
FLW 5 0.4 gsy Topical					
	Calcium chloride	0.153	0	22	8
14	Durasoil®	0.157	13	19	5
15	Envirotac II®	0.221	0	0	5
16	Water	0.195	0	0	5
17	Soiltac®	0.235	0	0	4
FLW 28 0.8 gsy Admix					
18	Surtac®				
19	Durasoil®				
20	Envirotac II®				
24	Water				
Washrack 0.4 gsy Topical					
21	Calcium chloride	0.188	0	4	7
22	Durasoil®	0.525	0	0	5
23	Surtac®	0.784	0	0	4
25	Envirotac II®	0.619	0	0	4

220-Day Unsurfaced Road Condition Index Survey

Test sections were evaluated for surface distresses using the unsurfaced road condition survey using specifications outlined in the U.S. Army TM 5-626 (Table 24). Each of the roads containing test sections was rated in good condition. Recent maintenance had removed surface distresses that were evident during the previous evaluations. URCI values ranged from 83 to 93 for all sections other than Section 9. This section required addition of aggregate to reestablish the necessary grain size distribution to stabilize the road surface. Surface distresses possibly attributed to the presence of dust palliative in the road existed on sections containing Surtac®. Admix construction methods using this product had a higher number of potholes in the road surface. The water-soluble sugar may soften the road after precipitation and lead to the formation of potholes on the road surface. This observation was much more prevalent during the previous testing interval. Other fluctuations in the URCI rating were generally caused by drainage conditions and road profile. Each of the sections was covered in loose aggregate and had similar severity levels of dust.

Table 24
220-Day Unsurfaced Road Condition Index

	Distress Types																					
	Improper Cross Section (lin ft)			Inadequate Roadside Drainage (lin ft)			Corrugations (sq ft)			Dust			Potholes (No.)			Ruts (sq ft)			Loose Aggregate (lin ft)			
	Distress Quantity and Severity																					
Section	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	URCI
1	600			600							X								1200			89
2	600			1200							X		1	1					1200			85
3	600			1200							X								1200			89
4	600			800	400						X		6	9					1200			83
5	600			1200							X		35	15					1200			85
6	600			800	400								4						1200			89
7	600			1200							X		2						1200			87
8	600			800	400						X		40						1200			85
9	600			1200							X								1200			62
10				1200							X								1200			91
11	600			1200							X		6						1200			87
12	600			1200							X		12						1200			87
13	600			1200						X			6						1200			88
14				1200							X								1200			91
15				600							X								1200			91
16	600			600	600						X								1200			87
17	600			600							X								1200			89
18	600			1200							X								1200			89
19	600			1200							X								1200			89
20	600			1200							X								1200			89
21				600							X								1200			91
22											X								1200			93
23				600							X								1200			91
24	600			1200							X								1200			89
25											X								1200			93

5 Data Analyses

Data for all of the evaluation periods were compiled and analyzed to determine the effectiveness of both dust palliatives and construction procedures for reducing dust during vehicle traffic. Soil property measurements were also analyzed to determine what effect, if any, the dust palliatives had on the physical properties of the soil.

Soil Data Analyses

Soil properties were characterized using strength measurements obtained from a DCP and moisture content and density data obtained from a nuclear density gauge. Each test was used to identify potential deterioration of the road structure within the test sections and to prevent falsely attributing poor product performance to distresses caused by other variables.

Table 25 provides a summary of the CBR values of the road surface and subgrade as determined by the DCP. All data suggest that each road section possessed a high bearing capacity in the aggregate-surfaced layer and moderate strengths in the underlying subgrade. Data also suggest that the admix construction method caused a reduction in strength in the disturbed layer. Sections 1 and 4 had lower CBR values at the surface after construction than during the initial evaluation. Later evaluations showed an increase in strength to a CBR of 100 percent. Further densification from heavy traffic most likely caused these increases to occur. Other data of particular interest were the CBR values of Section 9 after construction. The incorporation of excess fines into the road surface severely weakened the road surface on this section. Test sections using topical applications of dust palliatives did not have significant fluctuations in strength throughout the evaluation period.

Table 26 provides a summary of the data obtained from the moisture density gauge for each evaluation period. Trends within the data included a general increase in moisture content and density during subsequent evaluations. The higher moisture content of the road was most likely influenced by the environmental conditions during testing. The later evaluations were preceded by precipitation that saturated the road. Densification of the road was expected to occur from the heavy traffic, especially for sections that were constructed using the admix method. Sections constructed using the topical application method did

Table 25
Summary of DCP Data

Section	Surface					Subgrade				
	Pretreatment	Post-treatment	30-Day	80-Day	220-Day	Pretreatment	Post-treatment	30-Day	80-Day	220-Day
1	100	80	85	100	100	20	40	70	*	*
4	100	70	60	80	100	*	20	40	20	20
7		100	100	100			*	12	*	
8	100	100	100	100	100	*	*	18	*	10
9			10					15		
12	100	100	100	100	100	*	*	*	*	60
14		100	100	100			*	100	100	
16	100				100	*				*
17		100	100	100			*	100	100	
19		100	100	100			*	100	25	
20	100	100	100	100	100	*	*	100	100	*
22		50		85	100		15		30	*

* Inability of DCP to penetrate road surface prevented determination of subgrade strength.

Table 26
Summary of Moisture and Density Data

Section	Moisture Content (%)					Dry Density (pcf)				
	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day
1	4.4	5.1	5.8	6.4	6.9	132.3	127.7	127.4	134.9	127.7
2	4.8	4.0	5.0	5.4	8.6	132.6	132.3	135.0	138.1	125.0
3	7.4	7.2	6.4	8.7	10.0	121.8	119.6	122.3	124.1	120.2
4	4.8	6.1	9.8	8.2	6.7	131.8	120.8	121.2	124.3	130.7
5	3.5	3.7	5.2	4.6	5.7	135.5	131.6	134.4	136.5	134.7
6	5.9	7.4	8.4	5.8	6.1	125.4	120.5	123.0	136.2	133.3
7	4.3	4.8	6.4	7.4	8.6	133.3	131.0	124.5	131.5	130.2
8	3.0	4.3	5.3	6.0	6.9	137.5	129.7	133.9	136.0	130.0
9	7.6	6.6	12.8	11.6		123.9	119.7	119.0	121.5	
10	4.0	3.0	4.5	6.1	5.8	134.2	124.1	132.9	133.9	133.1
11	3.5	3.6	5.5	5.7	5.8	133.6	130.3	134.6	136.6	136.8
12	2.8	3.2	4.7	5.5	5.6	132.7	128.2	134.1	134.7	135.3
13	4.2	3.2	4.1	5.7	6.9	134.7	135.2	136.2	135.3	133.8
14	3.9	4.5	4.5	5.5	5.5	134.1	131.3	134.4	134.4	136.3
15	3.6	2.6	4.2	4.9	4.8	134.7	135.5	135.1	139.1	136.1
16	3.8	5.2	7.6	7.0	7.0	135.7	131.9	126.2	131.1	132.5
17	2.8	4.0	3.8	5.6	5.3	134.7	131.7	131.9	134.7	137.3
18	3.0	5.5	5.3	5.6	7.1	138.1	125.7	127.5	127.3	133.6
19	5.7	5.4	5.7	7.8	6.6	129.9	130.6	131.6	130.0	134.6
20	5.4	5.2	5.3	7.4	7.8	127.9	128.5	131.5	132.6	125.6
21	3.7	3.3	3.7	5.3	5.8	139.3	136.7	137.9	137.6	137.2
22	3.5	3.7	3.4	6.6	5.3	143.2	143.4	140.5	140.0	142.4
23	5.5	8.2	3.4	8.3	7.4	134.1	124.8	141.1	128.5	135.5
24	3.5	4.1	4.9	7.3	6.7	131.8	129.7	132.7	135.3	131.1
25	2.5	3.0	4.7	5.7	5.5	142.9	138.4	138.0	140.2	141.6

not have significant increases in density. No structural deterioration was noticed that could have caused reductions in the performance of the dust palliatives, but the high concentrations of moisture in the road during the last two evaluations may have provided some additional dust mitigating properties, thereby masking the ability of the palliatives to control dust.

Dust Collection Data Analyses

Two methods of dust particle collection were used to evaluate the ability of the palliatives to suppress dust. The mobile dust collection system provided continual measurement along the length of the test section. Stationary dust collectors placed on the shoulder of the road in the center of the test section collected dust particles the entire time that they remained suspended in the air above the road. The following paragraphs discuss the results from each of these systems and the effectiveness of the dust palliatives and their construction methods.

Stationary Dust Collection Data Analyses

Table 27 provides a summary of the stationary dust collection data along with the visual ratings associated with each test section for all evaluation periods. The total weight of dust collected is reported along with the percentage of reduction in dust from the pretreatment data. The following paragraphs discuss the results from these data and potential sources of error associated with the data. The visual rating scale assumed all sections to be in their worst state prior to palliative placement and free of any dust following treatment. Section 9 was not evaluated after the initial evaluation because of the extremely poor ride quality of the road and potential damage to testing equipment.

Sections 1 through 8 were constructed using the 0.8-gsy admix construction method. These sections were expected to provide the greatest reduction in dust from the larger quantities of product used as well as from greater dispersion of the product throughout the road surface. All products eliminated dust after construction. Performance was differentiated by the length of time for which the products maintained effectiveness.

The polymer emulsions (Sections 1 through 4) remained effective for 30 days after treatment. Later evaluations showed deteriorated road surfaces and reduced effectiveness for mitigating dust. During the 30-day evaluation the polymer sections had developed ruts in the wheelpaths of greater than 1 in. Most of the sections had a polished surface, but aggregate was beginning to dislodge. These occurrences did not have a direct effect on the amount of dust generated, but the mechanism of dust mitigation for polymers is derived from its soil binding characteristics. Traffic loads heavy enough to cause rutting and loose aggregate could disrupt some of the bond characteristics of the soil-polymer matrix. During the final evaluation it was unable to visibly differentiate among product performance or to observe noticeable differences in performance over untreated sections.

Table 27
Summary of Stationary Dust Collection Data

	Dust Collected (g)					Reduction from Pre Treatment Data (%)				Visual Rating				
Section	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day	Post Treatment	30-Day	80-Day	220-Day	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day
1	1.027	0.047	0.580	0.754	0.473	95	44	27	54	1	10	7	7	5
2	1.224	0.061	0.100	0.698	0.317	95	92	43	74	1	10	9	6	5
3	1.279	0.185	0.732	0.415	0.520	86	43	68	59	1	10	6	6	4
4	1.560	0.134	0.319	1.354	0.371	91	80	13	76	1	10	7	4	6
5	0.855	0.058	0.159	0.346	0.654	93	81	60	24	1	10	8	4	4
6	1.631	0.003	0.033	0.464	0.187	100	98	72	89	1	10	10	7	9
7	0.846	0.006	0.198	1.051	0.347	99	77	0	59	1	10	9	3	4
8	1.040	0.022	0.161	1.461	0.618	98	85	0	41	1	10	9	4	4
9	2.518	1.744				31				1	10			
10	1.491	0.196	0.456	0.860	0.403	87	69	42	73	1	10	7	7	4
11	1.598	0.357	0.079	0.037	0.399	78	95	98	75	1	10	9	9	4
12	0.810	0.266	0.187	0.551	0.737	67	77	32	9	1	10	9	8	4
13	1.229	0.054	0.326	0.048	0.164	96	73	96	87	1	10	7	9	8
14	1.368	0.050	0.165	0.030	0.483	96	88	98	65	1	10	9	8	5
15	1.280	0.060	0.764	0.398	0.553	95	40	69	57	1	10	5	6	5
16	1.061	0.281	0.724	0.113	0.646	74	32	89	39	1	10	5	7	5
17	1.749	0.074	0.431	0.105	0.626	96	75	94	64	1	10	6	6	4
18	2.016	0.136	0.151	1.746		93	93	13		1	10	9	5	
19	2.264	0.084	0.055	0.926		96	98	59		1	10	10	6	
20	1.266	0.432	0.409	0.383		66	68	70		1	10	6	8	
21	0.654	0.052	0.047	0.509	0.235	92	72	62	64	1	10	10	3	7
22	0.637	0.018	0.181	0.062	0.934	97	81	91	0	1	10	9	9	5
23	0.756	0.081	0.143	0.241	0.402	89	53	62	47	1	10	9	9	4
24	1.348	1.658	0.634	0.658		0	59	13		1	10	3	3	
25	1.197	0.081	0.486	0.149	0.377	93	53	88	69	1	10	4	7	4

Section 5 containing the polysaccharide solution performed well during initial testing but deteriorated rapidly under heavy traffic and frequent precipitation. During the 30-day evaluation this product was in good condition. Dust generation was low and the surface of the road was mainly intact. Minor rutting in the wheel paths occurred from densification of the road surface. Because this product is soluble in water, it remained workable and allowed loose aggregate to be reintroduced into the road. However, during the 80- and 220-day evaluations this section did not perform well. A very large number of potholes developed during the interval from 30 to 80 days after construction. The sugar may have softened the road surface immediately following precipitation and caused surface distresses to develop. Dust mitigating properties were also reduced during this period. During the final evaluation, detection of the treated area based upon dust suppression was not possible.

Section 6 contained the calcium chloride solution. This product had the best performance in nearly all of the evaluations. It did appear to lubricate the soil and cause some moderate rutting, but the dust reduction was excellent for the entire 220 days after construction. The 80- and 220-day evaluations took place following days of rainfall, so the performance of this section may have been enhanced by the availability of moisture and its ability to retain that moisture for longer periods of time than other products.

The two synthetic fluids placed on Sections 7 and 8 were initially very effective but did not perform well during the 80- and 220-day evaluations. During the 30-day test both of these sections were noticeably darker in color than the surrounding soil. Also, the road surface remained workable because these products do not cure, allowing any loose aggregate to be reintroduced into the road surface with traffic. Similar observations were made during the 80-day evaluation, but the presence of dust on the road sections was much more noticeable. There was no visible evidence of the product location for either section during the final evaluation. Dust concentrations on these sections were similar to untreated areas.

Sections 10 through 12 were constructed using the same process as the first sections but using half the quantity of dust palliative. For Sections 10 and 12, the performance was worse than sections using the same products at a higher application rate for all evaluation periods. Section 11, however, performed better than the test section constructed using the same product at a higher application rate. This occurrence was not anticipated and may have been caused by variations in vehicle traffic or testing conditions. It was supported by visual observations made during testing.

Some topical applications did not appear to perform significantly different from sections constructed using the admix method. Both the section containing calcium chloride and Durasoil® were effective for the first 80 days. These sections also had a noticeable color difference from the adjacent soil. The topical application of calcium chloride maintained its effectiveness for 220 days. Other sections in this location had performance visibly indistinguishable from untreated areas. The polymer emulsions did not perform well when placed topically. They were unable to withstand the heavy traffic, and the loose aggregate on the surface caused additional abrasion to the road.

Sections 18 through 20 and 24 were replicate sections to previously placed items. They were located on a separate road that had a higher traffic volume. However, the data from these sections were inconsistent with data from the similar sections. Some products produced more dust while others performed better in some evaluations. Visual evidence suggests that these road sections were not as dusty as those in the first location. Data from Sections 19 and 20 agree with this observation on both 30- and 80-day evaluation intervals. Data from Section 18 were similar to Section 5 after 30 days, but a significantly greater amount of dust was collected during the 80-day period. Data were not collected during the final evaluation for these sections.

Data from the sections located near the washrack were inconsistent. One factor may have been the unobstructed location of the sections. Wind velocities were generally much higher for this area. Greater wind speeds allowed less time for dust clouds to remain in the air near the particle collectors. Additionally, these sections were frequently maintained using a motor grader during the evaluation period. These topical applications were disturbed, and the distribution of the product may have been altered. Visual observations suggest that calcium chloride and Durasoil® were effective in mitigating dust for up to 80 days in these areas.

Mobile Dust Collection Data Analyses

Data from the mobile dust collection system are summarized in Table 28 along with the visual ratings associated with each test section for all evaluation periods. The total weight of dust collected is reported with the percentage of reduction in dust from the pretreatment data. The following paragraphs discuss the results derived from these data and potential sources of error associated with the data. The visual rating scale assumed all sections to be in their worst state prior to palliative placement and free of any dust following treatment. Section 9 was not evaluated after the initial evaluation because of the extremely poor ride quality of the road and potential damage to testing equipment.

The mobile dust collection system generally collected less dust than the stationary dust collection system. Not only were two collectors used for the stationary system to gather more dust, but also the mobile system relied on a very short time period for dust to leave the road surface and reach the height of the intake nozzle on the vacuum. Stationary collectors remained in the dust cloud that was generated by the test vehicle and had a longer duration to pull soil particles from the air.

The mobile dust collection system also was more critical of product performance. Because the stationary collectors had larger amounts of dust initially, it took longer for those initial values to be obtained as the products decreased in effectiveness. The mobile dust collection system did not capture the severity of the dust initially, and later collection values showed rapid

Table 28
Summary of Mobile Dust Collection Data

Section	Dust Collected (g)					Reduction from Pre Treatment Data (%)				Visual Rating				
	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day	Post Treatment	30-Day	80-Day	220-Day	Pre Treatment	Post Treatment	30-Day	80-Day	220-Day
1	0.241	0.053	0.102	0.061	0.243	78	58	27	0	1	10	7	7	5
2	0.131	0.015	0.048	0.095	0.173	89	63	43	0	1	10	9	6	5
3	0.172	0.096	0.076	0.041	0.386	44	56	68	0	1	10	6	6	4
4	0.182	0.060	0.066	0.213	0.258	67	64	13	0	1	10	7	4	6
5	0.141	0.061	0.039	0.185	0.214	57	72	60	0	1	10	8	4	4
6	0.155	0.023	0.034	0.134	0.093	85	78	72	40	1	10	10	7	9
7	0.162	0.025	0.038	0.247	0.325	85	77	0	0	1	10	9	3	4
8	0.162	0.067	0.031	0.116	0.233	59	81	0	0	1	10	9	4	4
9	0.214	0.288				0				1	10			
10	0.219	0.089	0.055	0.078	0.211	59	75	42	4	1	10	7	7	4
11	0.127	0.117	0.052	0.048	0.212	8	59	98	0	1	10	9	9	4
12	0.119	0.063	0.055	0.041	0.226	47	54	32	0	1	10	9	8	4
13	0.140	0.025	0.148	0.020	0.153	82	0	96	0	1	10	7	9	8
14	0.180	0.020	0.052	0.046	0.157	89	71	98	13	1	10	9	8	5
15	0.191	0.033	0.066	0.044	0.221	83	65	69	0	1	10	5	6	5
16	0.188	0.046	0.085	0.038	0.195	76	55	89	0	1	10	5	7	5
17	0.219	0.031	0.121	0.050	0.235	86	45	94	0	1	10	6	6	4
18	0.194	0.032	0.084	0.217		84	57	13		1	10	9	5	
19	0.190	0.028	0.020	0.168		85	89	59		1	10	10	6	
20	0.175	0.065	0.092	0.098		63	47	70		1	10	6	8	
21	0.131	0.024	0.027	0.063	0.188	82	79	62	0	1	10	10	3	7
22	0.413	0.020	0.055	0.051	0.525	95	87	91	0	1	10	9	9	5
23	0.409	0.047	0.047	0.164	0.784	89	89	62	0	1	10	9	9	4
24	0.155	0.145	0.175	0.290		6	0	13		1	10	3	3	
25	0.251	0.064	0.092	0.256	0.619	75	63	88	0	1	10	4	7	4

deterioration in product performance. Also, some concern existed about the mobile dust collection system having dust enter the intake nozzle after the vehicle had entered the untreated transition zones even after the vacuum had been turned off. Both systems have potential sources of error and must be analyzed in conjunction with visual data to determine the overall effectiveness of a product.

Mobile dust collection data for the polymer emulsion sections placed at 0.8 gsy using the admix construction method (Sections 1 through 4) generally agree with data from the stationary dust collection system. These sections performed well for the first 30 days, but heavy traffic deteriorated the road surface and caused an increase in the amount of dust during the 80-day evaluation. The final evaluation exhibited amounts of dust collected similar to the initial values.

Data for the remaining sections placed using 0.8 gsy and the admix construction method (polysaccharide, calcium chloride, and synthetic fluids) were similar to those obtained from the polymer emulsion sections. Performance was excellent during the post-treatment and 30-day evaluations, but the 80- and 220-day evaluations showed little to no benefit on dust generation. Only the visual observations for the calcium chloride section refute these data.

Sections placed with 0.4 gsy using the admix construction method (Sections 10 through 12) gave similar results with the exception of the 80-day evaluation. Data for this period suggest that these products (Soiltac®, Envirotac II®, and Surtac®) still performed excellently. These data do not coincide with visual observations made during the test sequence. These sections were perceived to produce more dust than sections with the same products placed at the 0.8-gsy application rate.

Sections 13 through 17 (0.4-gsy topical) also have data similar to previous sections. Dust generation was minimal during the first three evaluations following construction but significantly higher during the 220-day test. These data include the results from the control section (Section 16). This observation accounts for the reduction in dust collected for test sections during the first three evaluations because it would not be expected that the control section produced less dust over time. However, environmental influences such as the moisture content of the road could have an effect on the total amount of dust escaping from the road surface. Visual observations may not account for this difference because they are based on the relative perception of each test section during each testing period and are not necessarily consistent over the course of the entire project. The data do contradict the relative observation made that the calcium chloride section was more effective throughout the test than other sections, especially the control section and the polymer emulsion section.

Trends observed for previously mentioned sections were not maintained for Sections 18 through 20 and 24 (0.8-gsy admix). These data correlate with stationary dust collection data and suggest that performance of the dust palliatives was excellent for the post-treatment and 30-day collection intervals but greatly deteriorated during later tests. These data also show significant benefit of the dust palliatives over the control section (Section 24) during the early tests. These sections could not be tested during the 220-day evaluation because of heavy rainfall.

Data collected from the washrack area (Sections 21 through 23 and 25) were similar to most data obtained from the stationary dust collection system. They showed good performance of all of the products for the first three periods with dust values greater than the pretreatment values during the 220-day collection interval.

Discussion

Data from each of the dust collection systems along with visual observations and soil property measurements were analyzed to form opinions on the effectiveness of the eight dust palliatives monitored during this study. The presence of many variables during testing creates difficulty in accurately quantifying results, and the data must be supported by qualitative observations. The following paragraphs discuss the benefits and concerns for each type of chemical used for dust mitigation.

The soil property data showed no major differences in site conditions that would benefit or hinder product performance. The road strength and density was relatively consistent throughout all testing locations. Locations for test sections were selected to avoid sharp changes in elevations, areas where acceleration or deceleration would occur, and low lying areas with poor drainage. Based upon the information obtained during testing, it is inferred that the ability of the dust palliatives to suppress dust in the soil type and environment evaluated is based solely on performance and not differences in quality of the site locations.

The polymer emulsions provided excellent dust mitigation for early periods, but their performance diminished at testing periods of 80 and 220 days after construction. These materials adhere to soil particles and provide bonding. The heavy wheeled and tracked vehicles were able to break the bonds at the road surface and dislodge aggregate though abrasive action. Loose aggregate on the surface provided additional contact surfaces for traffic loads to grind surrounding bonded soil into particle sizes capable of producing dust. Once the soil-polymer matrix is disturbed it cannot be rejuvenated without the addition of more polymer emulsion.

The polysaccharide solution was the least effective material tested. It did not appear to bind soil particles as effectively as the polymer emulsions, and it did not provide moisture retention as effectively as the calcium chloride. The surface of this test section remained more workable than the polymers, and the traffic on the road either did not produce loose aggregate or compacted loose aggregate when it was dislodged. The deterioration of the dust mitigating properties was not considered to occur from the abrasive action of aggregate as it was with the polymer emulsions. The polysaccharide did not provide the necessary cohesion of dust particles to prevent them from escaping the road surface.

The calcium chloride provided the best dust suppression throughout the evaluation. The surface of test sections treated with this product retained a wet appearance characterized by a darker color than surrounding soil. For this product the mechanism of dust mitigation is retention of moisture, and the conditions at the test location were ideal for its properties. Performance was most likely enhanced by precipitation that occurred prior to the 80- and 220-day evaluations. The moisture on other sections evaporated more rapidly and provided acceptable levels of dust for testing. The calcium chloride did not appear to have a significant reduction in concentration caused by leaching from the road. However, tests were not run to evaluate the magnitude of this occurrence. Additionally, some collection in drainage water is expected to occur. No tests were performed to evaluate the corrosive nature of this chemical and the effect it may have on vehicles traveling roads where it was applied.

The synthetic fluids were very effective for short-term use, but did not provide good results during 80- and 220-day evaluations. These materials remain fluid in the soil and increase its workability. They have slight adhesive properties, and their performance may have been affected by their ability to transfer dust from tires of vehicles entering the test sections from untreated areas. During the 30-day evaluation observations were made that the ends of the test sections containing the synthetic fluids had a lighter color and contained more dust. Dust may have been tracked onto these sections from adjacent areas, affecting their perceived performance. Neither of the products was visibly distinguishable during the 220-day evaluation.

The calcium chloride was the only product with excellent performance 220 days after construction. All of the other sections would need to be maintained to rejuvenate the products. This procedure would be more effective if the road was graded and compacted to reestablish a smooth surface. Subsequent topical application of the palliatives could be made at reduced quantities to regain effectiveness. Only the synthetic fluids are expected to have complete accumulation of product with additional treatments. Both the polysaccharide and calcium chloride will potentially be dissolved in drainage water, reducing their concentrations over time. Reapplication may be necessary to reach their initial concentrations. The polymer emulsions will remain in the soil, but if the bond between the polymer and soil is broken it cannot be reintroduced. Further application of the polymer can help to bind those soil grains that have been removed form the soil-polymer matrix and reestablish the network.

6 Conclusions and Recommendations

The ERDC was tasked by the U.S. Marine Corps Systems Command to develop dust control systems for lines-of-communication (LOC) and base camp operations that would be suitable for use in temperate climates. This project consisted of field testing dust suppression chemicals and their application procedures. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This document addresses the testing that was performed to evaluate commercial dust palliatives and construction procedures for maintaining LOCs. The field test of dust palliatives discussed in this report was conducted at Fort Leonard Wood, MO, during the period September 2004 to April 2005 by the ERDC, Vicksburg, MS. This report summarizes the construction, trafficking, and monitoring of 25 field test sections designed to evaluate eight commercially available dust palliatives as well as their placement procedures and application rates. Palliative effectiveness was evaluated using dust particle collection equipment as well as visual observations of product performance. Pertinent conclusions from the testing conducted are noted below, and recommendations for selecting dust abatement methods and materials are provided in the following text.

Conclusions

The following conclusions were derived from the application and testing of selected palliatives from September 2004 to April 2005:

a. An Etnyre asphalt emulsion distributor was an effective piece of equipment for spraying each of the dust palliatives. It provided a controlled application rate with even distribution. However, using the polymer emulsions in the equipment may cause maintenance problems if the polymers begin to harden in the tank or within the distribution pipes or valves.

b. A TEREX soil reclaimer/stabilizer provided excellent mixing for incorporating each dust palliative in the respective road section. It also provided precise control over the tilling depth.

c. A 12-ton vibratory compactor was unable to achieve the original density of the road sections with only three coverages. Compactors with more mass may be required to achieve maximum density without extending the construction time resulting from additional coverages.

d. Performing topical applications of calcium chloride, Durasoil®, and Envirokleen® can provide adequate dust mitigation for 30 days on roads with a high load-bearing capacity.

e. For crust-forming products such as the polymer emulsions and Surtac®, topical applications are unable to withstand abrasion from heavy traffic, and disintegration of the surface crust reduces the product effectiveness.

f. Products placed topically at the 0.4-gsy application rate performed well where adequate bearing capacity existed.

g. Products placed at the 0.4-gsy application rate using the admix procedure did not provide adequate dust control for long-term use.

h. Each dust palliative provided some reduction in dust when compared with untreated road sections.

i. Calcium chloride was the most effective dust palliative for all application methods.

j. Unpaved roads with soil densities approaching their maximum value are subject to a reduction in their load-bearing capacity if treated using the admix procedure. The inability of the compaction process to reestablish the soil density can lead to faster deterioration of the road surface.

k. Frequent exposure to precipitation is detrimental to the performance of Surtac®. The product did not provide moisture resistance and led to an enhanced deterioration rate of the road surface when placed with the admix procedure.

l. Detrimental leaching of calcium chloride was not observed during this test.

Recommendations

The following recommendations are given based upon the results of the field tests:

a. Calcium chloride, Durasoil®, and Envirokleen® can be placed using a topical application only. Using the admix procedure will greatly complicate construction effort without providing comparable benefits in performance.

b. Envirotac II®, M10 + 50®, Soil~Sement®, Soiltac®, and Surtac® should be placed using the procedure *spray/till/compact/spray*. Admixing these chemicals will help to stabilize the soil and prolong their effectiveness. The final spray application will provide a greater concentration of product on the surface to resist traffic abrasion.

c. A distribution system comparable to the asphalt emulsion distributor is recommended for applying dust palliatives on roads. The system must be capable of holding significant volumes of fluid and evenly dispersing the fluid via fan-type spray nozzles. Mechanical pumps must be able to generate pressures capable of providing even dispersion across the road. The distribution system should be able to regulate the volumetric output of the fluids for application rate control. Minimum flow rates of 100 gpm are recommended for treating large areas.

d. A steel-wheeled vibratory compactor should be used with the admix construction method to consolidate aggregate roads. Coverages with the compactor should continue to be made until no significant change in the density of the road surface is observed.

e. A rotary mixer is recommended to mix dust palliatives into the soil at depth when using the admix construction method. Using a motor grader to mix soil and palliatives may not provide adequate dispersion of the product throughout the soil.

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Photo 1. Troxler 3430 nuclear density gauge

Photo 2. Dynamic cone penetrometer

Photo 3. Stationary dust collection system

Photo 4. Mobile dust collection system

Photo 5.   Etnyre asphalt emulsion distributor

Photo 6.   TEREX soil reclaimer/stabilizer

Photo 7. Caterpillar 12-ton vibratory roller

Photo 8. Moving 275-gal tote with TEREX forklift

Photo 9. Placement of traffic delineators for section identification

Photo 10. Section 1 after treating with Envirotac II® (0.8 gsy admix)

Photo 11. Section 5 after treating with Surtac® (0.8 gsy admix)

Photo 12. Section 6 after treating with calcium chloride (0.8 gsy admix)

Photo 13. Section 7 after treating with Durasoil® (0.8 gsy admix)

Photo 14. Section 13 after topical application of calcium chloride (0.4 gsy)

Photo 15. Section 14 after topical application of Durasoil® (0.4 gsy)

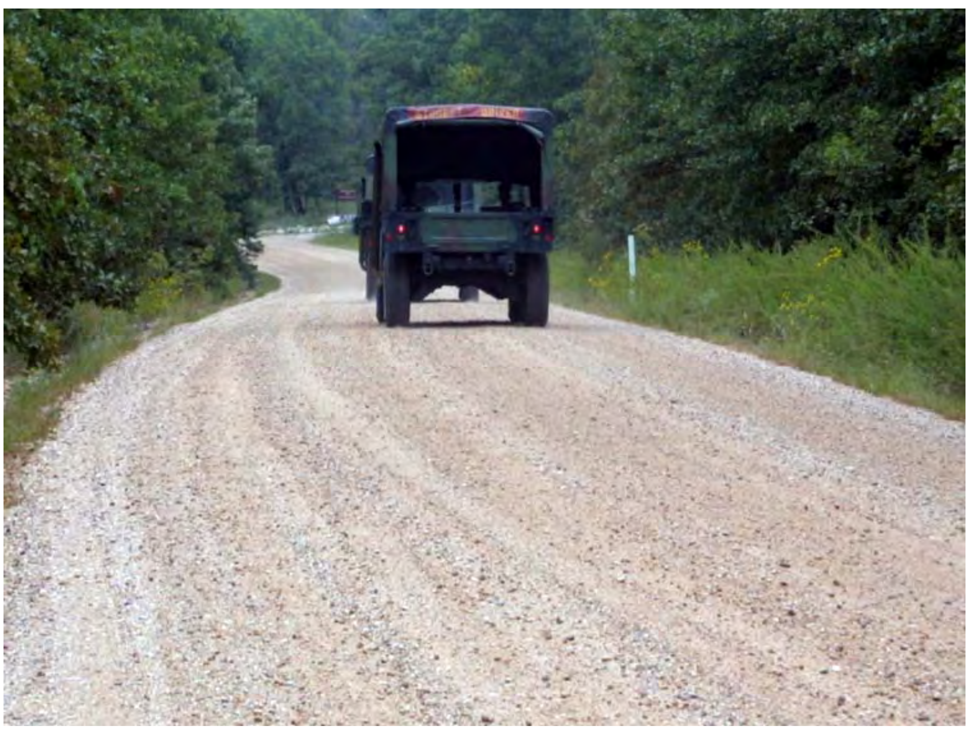

Photo 16. Section 15 after topical application of Envirotac II® (0.4 gsy)

Photo 17. Light dust on section 1 (Envirotac II® 0.8 gsy admix) during 30-day evaluation

Photo 18. Excellent dust reduction on section 2 (Soiltac® 0.8 gsy admix) during 30-day evaluation

Photo 19. Light dust produced on section 3 (M10 + 50® 0.8 gsy admix) during 30-day evaluation

Photo 20. Light dust produced on section 4 (Soil Sement® 0.8 gsy admix) during 30-day evaluation

Photo 21. Excellent dust reduction on section 5 (Surtac® 0.8 gsy admix) during 30-day evaluation

Photo 22. Absence of dust on section 6 (calcium chloride 0.8 gsy admix) during 30-day evaluation

Photo 23. Absence of dust on section 7 (Durasoil® 0.8 gsy admix) during 30-day evaluation

Photo 24. Absence of dust on section 8 (Envirokleen® 0.8 gsy admix) during 30-day evaluation

Photo 25. Dust generated on section 10 (Soiltac® 0.4 gsy admix) during 30-day evaluation

Photo 26. Dust generated on section 11 (Envirotac II® 0.4 gsy admix) during 30-day evaluation

Photo 27. Dust generated on section 12 (Surtac® 0.4 gsy admix) during 30-day evaluation

Photo 28. Dust generated on section 13 (Calcium Chloride 0.4 gsy topical) during 30-day evaluation

Photo 29. Dust generated on section 14 (Durasoil® 0.4 gsy topical) during 30-day evaluation

Photo 30. Dust generated on section 15 (Envirotac II® 0.4 gsy topical) during 30-day evaluation

Photo 31. Dust generated on section 16 (water 0.4 gsy topical) during 30-day evaluation

Photo 32. Dust generated on section 17 (Soiltac® 0.4 gsy topical) during 30-day evaluation

Photo 33. Dust generated on section 18 during 30-day evaluation

Photo 34. Dust generated on section 19 (Durasoil® 0.8 gsy topical) during 30-day evaluation

Photo 35. Dust generated on section 20 (Envirotac II® 0.8 gsy topical) during 30-day evaluation

Photo 36. Dust generated on section 24 (water 0.8 gsy topical) during 30-day evaluation

Photo 37. Dust generated on section 21 (calcium chloride 0.4 gsy topical) during 30-day evaluation

Photo 38. Dust generated on section 22 (Durasoil® 0.4 gsy topical) during 30-day evaluation

Photo 39. Dust generated on section 23 (Surtac® 0.4 gsy topical) during 30-day evaluation

Photo 40. Dust generated on section 25 (Envirotac II® 0.4 gsy topical) during 30-day evaluation

Photo 41. Rutting and dislodged aggregate in surface of section 1

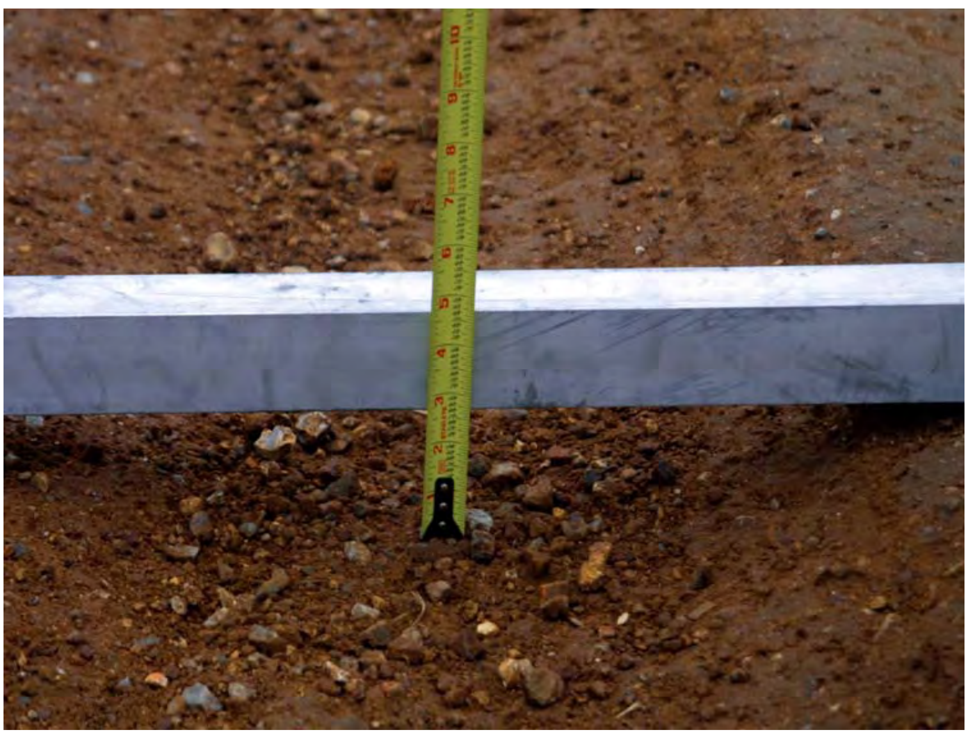

Photo 42. Densification of soil treated with calcium chloride in section 6

Photo 43.   Longitudinal cracking in surface of section 2

Photo 44.   Aggregate raveling on surface of section 11

Photo 45. Vehicle traveling on section 1 (Envirotac II® 0.8 gsy admix) during 80-day evaluation

Photo 46. Vehicle traveling on section 2 (Soiltac® 0.8 gsy admix) during 80-day evaluation

Photo 47. Vehicle traveling on section 3 (M10+50® 0.8 gsy admix) during 80-day evaluation

Photo 48. Vehicle traveling on section 4 (Soil Sement® 0.8 gsy admix) during 80-day evaluation

Photo 49. Vehicle traveling on section 5 (Surtac® 0.8 gsy admix) during 80-day evaluation

Photo 50. Vehicle traveling on section 6 (calcium chloride 0.8 gsy admix) during 80-day evaluation

Photo 51. Vehicle traveling on section 7 (Durasoil® 0.8 gsy admix) during 80-day evaluation

Photo 52. Vehicle traveling on section 8 (Envirokleen® 0.8 gsy admix) during 80-day evaluation

Photo 53. Vehicle traveling on section 10 (Soiltac® 0.4 gsy admix) during 80-day evaluation

Photo 54. Vehicle traveling on section 11 (Envirotac II® 0.4 gsy admix) during 80-day evaluation

Photo 55. Vehicle traveling on section 12 (Surtac® 0.4 gsy admix) during 80-day evaluation

Photo 56. Vehicle traveling on section 14 (Durasoil® 0.4 gsy topical) during 80-day evaluation

Photo 57. Vehicle traveling on section 15 (Enivortac II® 0.4 gsy Topical) during 80-day evaluation

Photo 58. Vehicle traveling on section 16 (water 0.4 gsy topical) during 80-day evaluation

Photo 59. Vehicle traveling on section 17 (Soiltac® 0.4 gsy topical) during 80-day evaluation

Photo 60. Vehicle traveling on section 23 (Surtac® 0.4 gsy topical) during 80-day evaluation

Photo 61. Section 9 (water 0.8 gsy admix) - medium improper cross section

Photo 62. Section 12 (Surtac® 0.4 gsy admix) - inadequate roadside drainage

Photo 63. Corrugations along curve in untreated area of road

Photo 64. Section 4 (Soil~Sement® 0.8 gsy admix) – medium dust

Photo 65. Section 5 (Surtac® 0.8 gsy admix) - low and medium potholes

Photo 66. Section 1 (Envirotac II® 0.8 gsy admix) - low rutting

Photo 67. Vehicle traveling section 1 (Envirotac II® 0.8 gsy admix) during 220-day evaluation

Photo 68. Vehicle traveling section 2 (Soiltac® 0.8 gsy admix) during 220-day evaluation

Photo 69. Vehicle traveling section 3 (M10 + 50® 0.8 gsy admix) during 220-day evaluation

Photo 70. Vehicle traveling section 4 (Soil~Sement® 0.8 gsy admix) during 220-day evaluation

Photo 71. Vehicle traveling section 5 (Surtac® 0.8 gsy admix) during 220-day evaluation

Photo 72. Vehicle traveling section 6 (calcium chloride 0.8 gsy admix) during 220-day evaluation

Photo 73. Vehicle traveling section 7 (Durasoil® 0.8 gsy admix) during 220-day evaluation

Photo 74. Vehicle traveling section 8 (Envirokleen® 0.8 gsy admix) during 220-day evaluation

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14. ABSTRACT

The U.S. Army Engineer Research and Development Center was tasked by the U.S. Marine Corps Systems Command to develop dust control systems for sustainment use on roads and other large-area applications in temperate climates as part of a comprehensive dust abatement program. The project consisted of evaluating various dust palliatives and application procedures during field tests. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This report addresses testing performed to evaluate commercial palliatives and application processes for constructing and maintaining lines-of-communication. Twenty-five test sections were constructed at Fort Leonard Wood, MO, using commercial palliatives for dust abatement. Several application procedures were evaluated in the process, including topical applications and admixture applications with alternate application rates. Each test section was evaluated at 0, 30, 80, and 220 days after construction. The evaluation consisted of dust particle collection and soil property measurements. Pertinent conclusions from the testing conducted are noted, and recommendations for selecting dust abatement methods and materials are provided.

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